OPTIMIZATION OF CUTTING PARAMETERS FOR MAXIMIZING TOOL LIFE

by

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CERTIFICATE

This is to certify that the thesis entitled "OPTIMIZATION OF CUTTING PARAMETERS FOR MAXIMIZING TOOL LIFE" is a record of the work carried out by Mr. I V. K Appa Rao under my supervision and that it has not been submitted elsewhere for the award of a degree

25.6.97

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Nomenclature

F_{xy}	: Thrust force(kgf)
F_z	: Cutting force(kgf)
F'_{xy}	: Component of thrust force in the absence of wear(kgf)
F_{tf}	: Component of thrust force in the presence of wear (kgf)
F_{cf}	: Component of cutting force in the presence of wear(kgf)
v	: Cutting velocity(m/min)
f	: Feed (mm/rev)
V_A	: Adhesion wear volume (mm^3)
V	: Wear volume (mm^3)
z	: Wear coefficient
BHN	: Birinal hardness of the material
b	: Width of cut(mm)
d	: Depth of cut(mm)
h_f	: Flank wear height (mm)
α	. Clearance angle
ψ	: Side cutting edge angle
γ	. Rake angle
t	· Cutting time(min)
M	: Maximum number of iterations
n	. Number of variables
$f(x)$	Objective function
$g(x)$	Constraint function
p, r	Penalty parameters

Abstract

Tool life improvement is the most desirable in metal cutting process. A small increase of tool life could lead to large savings in the time and cost of manufacturing. In the present work effort has been made on improving the tool life by the use of optimum cutting parameters during the machining process.

A tool life equation has been established with the help of experimental data and the adhesion wear model. Optimization technique has been used which maximizes the the tool life subjected to practical constraints. The experimental setup consists of Turning lathe, Dynamometer, Amplifier, A/D converter, and a PC. The analog signal of the cutting force from the dynamometer is amplified using a special purpose op-amp circuit. The amplified signal is converted to digital form by using analog to digital converter. A/D converter is interfaced to PC and the digital value of the cutting force so obtained is fed to the optimization program which gives optimized values of the velocity and feed. The machine is set to the optimum values of velocity and feed and the above process is repeated, until the flank wear reaches the threshold value signalling the end of tool life. The tool life is compared with that obtained when cutting process is carried out at certain values of velocity and feed comparable with the earlier one. It is observed that there has been a marked improvement in the tool life.

Chapter 1

Introduction

1.1 Introduction

Machining is the most versatile of the manufacturing processes. In the machining process the workpiece is brought to the desired size, shape, finish and accuracy through the removal of excess material from it in the form of chips. This is achieved by using a wedge shaped cutting tool of material harder than the workpiece. The inherent characteristic of machining process is the wear on the cutting tool which is undesirable, as it impairs the fitness of the tool. So far very little control could be achieved over the wear on the cutting tool.

Cutting tools have a limited life due to inevitable wear and consequent failure of the tool. The cutting tool is said to be failed when it is unable to cut, consuming large power, and cannot produce acceptable surface finish. The tool life is directly related to the tool wear and condition of the finished parts.

The various tool life criteria[1] are,

1. Chipping or fine cracks developing at the cutting edge

2. Total destruction of the cutting tool

3. Wear, land size on the flank of the tool

4. Crater depth, width or other parameters of the crater wear on the rake face of the tool

5. A combination of wear land size and crater depth

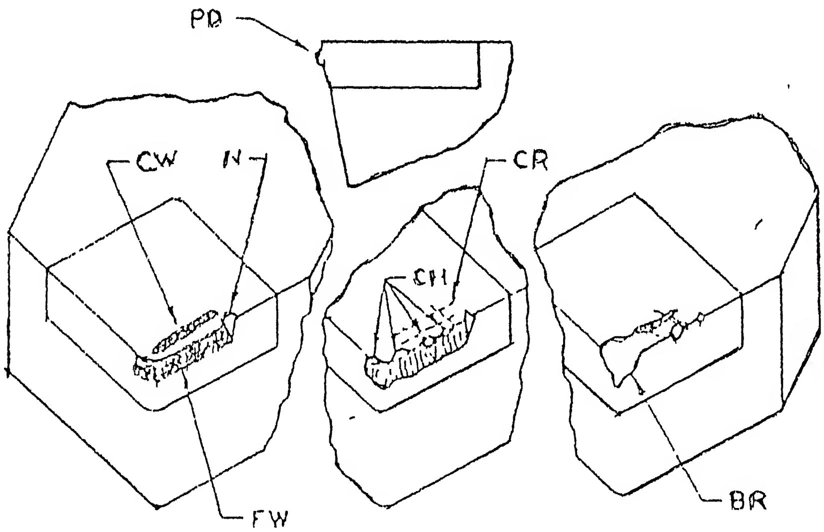
6. Volume of weight of material worn off the tool

7. Limiting value of surface finish produced on the component

8 Limiting value of change in component size

9. Fixed increase in cutting forces or power required to perform a function

Most often, tool life criterion is defined as a predetermined threshold value of the cutting tool wear. Clearly any development in the tool or work material for increasing tool life will be beneficial as it leads to a lot of savings in cost of manufacturing Continued efforts are being made to find a way of using the cutting tool to the greatest possible extent before it fails. In the present work, effort has been made on improving the tool life by minimizing



FW = Flank Wear CH = Chipping

CW = Crater Wear CR = Cracking

N = Notching BR = Breakage

PD = Plastic Deformation

Fig. 1.1 Types of tool wear ,Ref[14]

the growth rate of wear. Before going into the details, it is necessary to understand the nature of tool wear and wear mechanisms. Because of the basic similarity in the material removal mechanisms in different types of machining operations, turning operation has been widely used for studying the characteristics of the machining process. The present work performed on the turning is thus believed to provide a basic method which can later be used for other operations with appropriate modifications. The various types of wear a cutting tool may be subjected to are illustrated in Fig1.1. The failure of a cutting tool may be due to one or more of the following reasons[2].

1 plastic deformation of the tool due to high temperature and large stresses

2. mechanical breakage of the tool due to large forces and insufficient strength and toughness

3. blunting of the cutting edge of the tool through a process of gradual or progressive wearing action

Of the various types of tool wear, flank wear, FW , on the flank face and the primary cutting edge alongwith its accompanying notch, N , and crater wear on the rake face, CW, are classified as the regular types of tool wear due to their regular time related growth charcterstics. The other types of tool wear termed as irregular types, can generally be

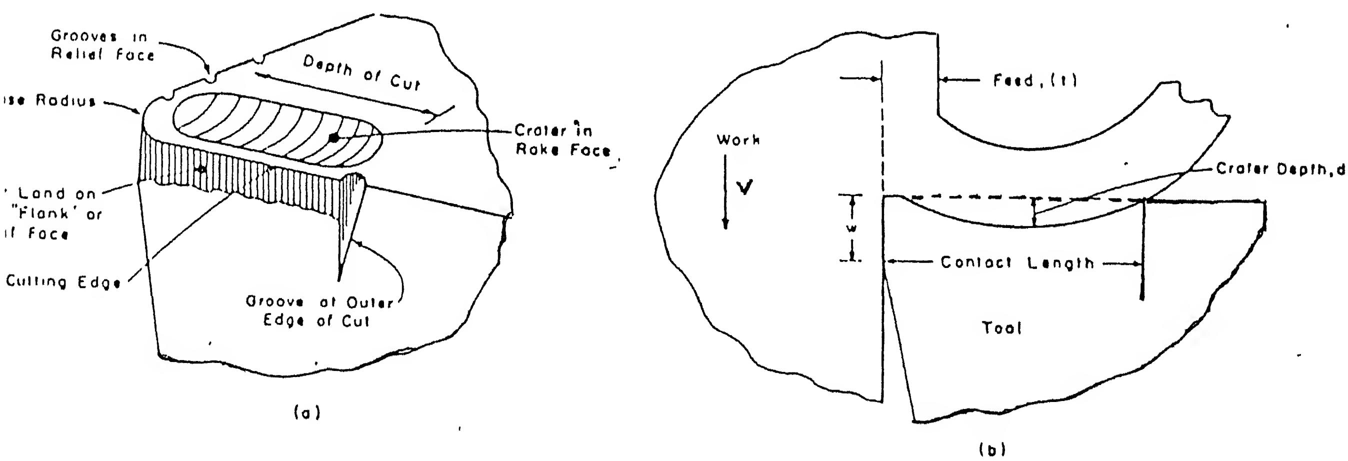


Fig. 1.2 Geometry of tool wear,Ref[3]

avoided by proper selection of tool material and cutting conditions. But whatever be the cutting conditions, regular types of wear will always occur, though at varying rates. Due to these reasons flank and crater wears have been the subject of most studies in the area of tool wear. Because of the progressive or regular types of wear, one or more of the following four wear zones appear on the cutting tool[3]as shown in Fig1. 2.

- the wear land is a more or less uniform wear zone on the flank of the tool. Despite the relief angles provided on the flank face of the cutting tool, some amount of rubbing between this face and the finished surface is always present forming the wear land. Width of the wear land is taken as the measure of the amount of flank wear.

- the crater wear is a dished-out section of the tool rake face and is formed due to the high contact stresses and high chip tool interface temperatures. The crater depth is generally maximum at a distance from the cutting tip, and the crater curvature corresponds to radius of the chip curvature. High speed cutting, leading to high temperatures, results in severe cratering. This eventually causes weakening of the tool dege and its fracture.

- the nose wear is formed at the nose radius and near the end relief face. The wear here is partially in continuation of the wear land around the nose radius. This contributes to the increased roughness of the finished part as wear progresses.

- a groove often forms at the outer diameter of the workpiece and can become quite large compared to the other wear zones. As it is not associated with the finished surface of the workpiece, this groove is not particularly harmful, except that it may affect the regrinding time.

Three main forms of progressive tool wear mechanisms were identified as adhesion, abrasion and diffusion wears. The wear between two rubbing surfaces occurs[2]due to

1. macrotransfer type mechanical wear process like abrasion and adhesion.

2. microtransfer type thermomechanical process like diffusion.

When the rubbing surfaces are free from any active chemical environment and the deteriorative action of emf is absent, the mechanical wear process contributes to the major share of the tool wear volume particularly at low rubbing speeds. Such mechanical wear takes place in two predominant ways.

1. abrasion due to ploughing of softer matrix by hard constituents such as segregated carbides, incusions etc.

2. adhesion and formation of metallic bonds formed over the rubbing surfaces under load and subsequent rupture of these bonds followed by transfer of these elementary particles.

Diffusion is a time and temprature dependent process and also depends on bonding affinity of the tool-work particle pair and the degree of atomic agitation. The high temprature generated at the tool-work contact areas leads to diffusion of the atoms from the high atomic density tool material to the lower atomic density workpiece material causing weakening of the surface of the tool.

1.2 Tool life and its improvement:

Economic implications of the machining operations have to be looked into to keep the cost of production as minimum as possible. One way of doing so is to improve the tool life. Improvement of tool life prevents frequent changing of the tool, and hence reduced number of set ups. Also the cost of regrinding is reduced. In totality, it will reduce the cost of production to the minimum acceptable level. The variables affecting the tool life are

1. Process variables - speed, feed and depth of cut

2. Tool material

3. Tool geometry

4. Workpiece material, its hardness and micro-structure

5. Surface condition of the work-piece

6. Cutting fluid

For a given work - tool combination and cutting condition the tool life can be improved by adjustment of the process variables like velocity, feed and depth of cut. The greater influence on the tool life is offered by velocity, feed and depth given in that order. However, the depth of cut on tool life is relatively less.

1.3 Constrained optimization methods[4]:

All engineering design and decision making problems have an objective of minimizing or maximizing a function and simultaneously have a requirement for satisfying some constraints arising due to space, strength, MRR, or stability considerations. The constrained optimization algorithms can be grouped into direct and gradient based methods. Some of these algorithms employ single variable and multivariable unconstrained optimization algorithms . A constrained optimization problem comprises an objective function together with a number of equality and inequality constraints. Often lower and upper bounds on design or decision variables are also specified. Considering that there are N decision variables, we write a constrained optimization problem as follows:

Minimize f(x)

subject to

$$g_j(x) \geq 0; where, j = 1, 2, \cdots J$$

$$h_k(x) = 0; where, k = 1, 2, \cdots K$$

$$x_i^l \leq x_i \leq x_i^v; where, i = 1, 2, \cdots N$$

This is the most general form of a single - objective constrained optimization problem The function f(x) is the objective function, which is to be minimized. The functions $g_j(x)$ and $h_k(x)$ are inequality and equality constraint functions, respectively. There are J inequality constraints and K equality constraints in the above problem We recognise here that a less than or equal type constraint can be transformed into the other type by multiplying the constraint function by -1. Since none of the above functions are assumed to be linear, the above problem is also known as Nonlinear Programming Problem or simply an NLP problem Even though the above problem is written for minimization, maximization problems can also be solved by using the duality principle Any point x(t) is said to have satisfied a constraint, if the left hand side expression of the constraint at that point agrees with the right side value by the relational operator between them A point is defined as a feasible point if all equality and inequality constraints and variable bounds are satisfied at that point. There are two ways an inequality constraint can be satisfied at a point - the point falls either on the constraint surface or on the feasible side of the constraint surface. If the point falls on the constraint surface, the constraint is said to be an active constraint at that point. In the latter case, the constraint is inactive at the point.

Constrained Optimization algorithms are divided into two broad categories namely direct search methods and gradient based methods Among the direct search methods, the penalty function method is mostly used. In the penalty function method, infeasible solutions are penalized by adding a penalty term in relation to the amount of the constraint violation at that solution. There are primarily two types of penalty functions- interior penalty functions which penalize only feasible solutions close to constraint boundaries and

exterior penalty functions which penalize infeasible points. The interior penalty methods requires an initial feasible solution, whereas the exterior penalty methods do not require the point to be feasible. This is why exterior penalty methods are more popular than interior penalty methods. The problem with the penalty function method is that it distorts the objective function in successive iterations. This problem of distortion of the objective function can be rectified by using a method of multiplier (MOM) strategy. In the MOM technique, the penalty is not added directly to the objective function, instead, some function of the penalty is added. The effect is a shift of the unconstrained objective function near the constrained optimum point. One added advantage of the MOM technique is that the final iteration can be directly used to compute the Lagrange multipliers corresponding to constraints. The complex search method is similar to the simplex search method for unconstrained functions except that the provisions are made to check the feasibility of Intermediate solutions. If the solutions are found to be infeasible, suitable modifications are adopted to make them feasible. Method of feasible directions[5] is constructed to deal with the inequality constraints. The basic idea is to choose a point satisfying all the constraints and to move to a better point according to the iterative scheme.

$$x(i+1) = x(i) + v * s(i);$$

where $x(i)$ is the starting point of the ith iteration. $s(i)$ is the direction of the movement, v is the distance of movement and $x(i+1)$ is the final point obtained at the end of ith iteration. The value of v is choosen such that i)a small move in that direction violates no constraint and ii) value of the objective function can be reduced in that direction. The point $x(i+1)$ is taken as the starting point for the next iteration and the procedure repeated several times until a point is obtained such that no direction satisfying both i) and ii) can be found. A direction satisfying i) is called feasible while a direction satisfying both the properties i) and ii) is called a usable feasible direction. The Frank- Wolfe algorithm linearizes the objective function and constraints at any point and solves the resulting LP

problem using a LP technique. A unidirectional search is then performed from the old point to the new point to find a better point. The objective function and constraints are linearized at this point and the search continues. Although this method is simple and straight forward, it may not work if the initial point is far away from the true optimum point, because the linearized constraint and the objective function may be very different than the true functions at a point away from the current point. The cutting plane method begins with a large search space formed by linear constraints. The resulting LP problem is solved and a linear cutting plane is formed using the most violated constraint at the resulting point. This is how cutting planes are formed at each iteration to reduce the initial large search space into the shape of the true feasible region. Since the cutting plane method always surrounds the true feasible search space with linear planes and the solution is obtained by using those linear planes as constraints, the obtained solution is always infeasible. Thus, sufficiently large number of iterations are required so that the solution, although infeasible, is very close to the true optimum soluttion. This method is not very efficient if the true optimum point is not a boundary point. A local exhaustive search can then be performed to find the true optimum solution.

The generalised reduced gradient method is a sophisticated version of the variable elimination method of handling eqality constraints. Some variables are expressed in terms of other variables called basic variables by using eqality constraints. The gradient of the objective function at any point is then expressed only nonbasic variables. This gradient is called the reduced gradient . This algorithm works very well for NLP problems with equality constraints only.

Another algorithm to handle equality constraints efficiently is to use the gradient projection method where each infeasible point, obtained by performing a unidirectional search, is projected onto the constraint surface to make the point feasible. Thus, the resulting points are always feasible. If two successive iterations produce the same point, the steepest descent method is adopted to check whether there is any better point inside the feasible

region.

Of all the mentioned methods each method has some advantages and limitations. Penalty function method is more widely used, Since it accomadates constraints of all types(greater than, less than, equal to). In the present work, this method has been chosen, since the algorithm works faster and the code of this method is available.

1.4 Literature review:

Although several efforts have been made to increase the tool life in the past decades by way of coating the tools etc, the new approach to improve the tool life by the on-line adoption of variable cutting parameters like speed and feed started, getting prominance during cutting only recently.

Balazinski and Ennajimi[6] investigated the influence of feed variation on tool wear during face milling. Their experiments on milling stainless steel 17 - 4 PH revealed that it is possible to increase the tool life substantially with a proper variation of the feed throughout the cutting process. Focus is made on the crater wear. A set of tests was performed to establish the range of cutting conditions applicable and another set to establish the effect of feed variation on tool wear. Comparision of tool wear was made in case of constant feed and variable feed for a constant material removal rate. Tool wear is found to reduce by 30%. Moreover, tool wear is more uniform in case of variable feed. The chosen cutting conditions of minimum tool wear are velocity = 99 m/min. and constant feed rate = 0. 8 mm/rev.

Mondalski[7] while studying the tool wear due to chipping and cratering noticed that it is possible to increase the tool life by varying the size of the chip contact length on the rake face of the tool, while machining. This has formed the basis for the further investigations in this area.

Songmene and Balazinski[8]performed experiments using variable feed on Inconel 600

in feed milling process. Results indicated that the most influential factors are amplitude and duration of each feed variation step, to decide the course of tool wear and hence the tool life. It was observed that at low cutting time, feed change at fixed instant has no influence. At high cutting time feed change at regular intervals influences the tool wear. A 10% sinusoidal feed variation cycle about the optimal feed, with 5 seconds incremental steps, increased the tool life by a minimum of 30%. The comparision was based on a constant material removal rate.

Jamielniak and Szafarczyk[9]showed by their experiments on carbide inserts that there is a substantial difference in the crater wear development when machining with different sequences of feeds. The results indicate a significant difference between the final crater depths with increasing and decreasing feeds. It is observed that the distance between the major cutting edge and the deepest point of the crater depends upon the feed sequence.

Takatsuto, etal[10] proposed a method to increase the tool life in drilling. The method includes the changing of feed in the descending order at regular intervals instead of constant feed process. An attempt was made to break the resulting chip material by utilizing the intermittently decelerated feed technique. It was found that the resultant chip could be broken into smaller, more easily disposable pieces by optimising the interval and rate of decelerated feed. A longer tool life was achieved using the intermettently decelerated feed technique.

Novak, Linkopong and Wilkund[11] proposed a new approach to improve the reliability of on-line prediction of tool life without the need of pre-process data suitable for implementation on a CNC lathe. A selected critical point on tool wear curve has been taken as criterion to assess the tool life. The modelling procedure is based on cutting force monitoring and flank wear measurements. The cutting force is represented by force ratio f(z)/f(y) where f(z) is the feed force component and f(y) is tangential force component. The tool wear is measured by means of a camera and is used to support cutting force monitoring. By this technique they deduced that traditional tool condition monitoring can be improved

by early prediction of the tool life with uncertainty of about 15% after 1. 5-2. 0 minutes of cutting.

Nagasaka and Hashimoto[12] proposed a new tool life equation. In this equqtion the cutting conditions and the amount of tool wear are treated as independent variables. The model is constructed so that it fits a process of tool which follow three stages, i. e. rapid intial wear followed by gradual or little wear and finally very rapid or catastrophic wear. The model is compared with multiplication and polynomial models with respect to the accuracy and the applicability to optimisation of the cutting process. A tool life equation is proposed which described the three stages of the wear process with a single mathematical model. The sensitivity of analysis of the model is considered by investigating the effect of variation of the parameters on its accuracy. The model for tool life prediction includes all the stages of wear.

Usui etal[13] established a wear characteristic equation. A wear characteristic is first derived theoretically and then verified experimentally. An energy method is devoleped to predict the chip formation and forces in turning with a single-point tool from orthogonal cutting data. Using these predicted results, stress and temprature on the wear faces was calculated. A function of wear rate, normal stress and temprature which includes two material constants, is proposed as the wear characteristic eqation for tungsten carbide tools and its propriety is demonstrated experimentally. The wear characteristic equation mentioned above is then utilized to predict analytically the wear progress and the tool life by applying the normal stress and the temparature predicted already for given cutting conditions. Computer simulation of the devolep ment of wear is carried out by using characteristic equation and the predicted stress and temperatures upon the wear faces. The predicted wear progress and the tool life are found to agree with experimental results.

Barrow[14] proposed criteria for acceptable tool life equations as the those:

1. which produce a good fit to experimental points.

2. which cater for wide range of cutting parameters, speed, feed, depth of cut

In order to satisfy the second criterion, the equations Barrow proposed are:

1. Extended taylor equation
2. Kronenberg's equation
3. All equations using the chip equivalent concept.
4. Konig depiereux equation.

Of these four, the equations using the chip-equivalent concept are particularly found to be useful since it considers machine variables(speed, feed and depth of cut)and also the tool approach angle and nose radius.

Rubenstein[15] made an analysis of tool-life based on flank-face wear. It has been shown that when cutting orthogonally at a fixed width of cut, the temprature in the clearance-face contact region can be represented as being proportional to cutting speed , feed, and flank wear land. He deduced that tool life will improve for a given work tool combinationas

1. the value of flank wear land criterion increases
2. the clearance angle of the tool increases
3. the angle tool increases.
4. the cutting edge radius decreases, i. e as the edge becomes sharper
5. the lubrication becomes more efficient.
6. cooling efficiency increases(provided this does not cause a built - up edge formation)
7. the duration of tool engagement decreases in interruped cutting and
8. the chip/rake-face contact length decreases with the use of restricted rack-face tools.

Cook[3] discussed the effect of chip - tool contact length on tool wear at length. His observations have shown that temprature increases with the increase in the length of contact between chip and tool, or crater length(roughly as square root). Thus anything that can reduce contact length may decrease temperature and therefore wear rates. It was mentioned that contact length can be reduced in two ways:

1. limiting the length of contact by cutting away the tool material at some distance from edge , or grinding the tool with a secondary rake to alter the stress pattern. the contact can often be reduced to about half its natural length in this fashion, usually with improved wear characteristic but more costly tool preparation.

2. causing the chip to curl more tightly and thus reduce the contact length This can be accomplished by increasing the rake angle by reducing chip- tool friction, and sometimes by cooling the back of the chip.

Leo etal[16] proposed a method to monitor the tool wear for its optimal control to ensure maximum tool life. They have correlated between the tangential force and flank wear. The dynamic tangential force shows a peak when seen in the frequency spectrum which corresponds to the resonant frequency of tool holder. Tracking of the peak revealed a trend in which force increases as the flank wear increases and it decreases as the tool starts to fail. The proposed method was found its use in systems like unmanned machining centres and flexible manufacturing systems.

Raman and Lakkaraju[17] proposed integration of tool life variables with optimisation studies to make the analytical NC path planning real. A two step process for analysing the tool path planning problem was carried out by the authors. They made a prototype program to include the effects of tool life variables on NC path planning. They concluded that by adding more variables and by performing more analysis on the software, the total simulation of the machining strategies can be chalked out analytically.

Closer study of the above works reveals that there has been substantial evidence in the view that tool life can be improved by adopting variable cutting parameters. Although

some efforts have been made to improve the tool life by variable feed technique, yet no attempt has been made to study the influence of both feed and cutting speed during machining on the tool life. Furthermore, a clear strategy of extent of variation in these parameters and their frequency is to be established.

1.5 Scope of present work:

In the present work effort has been made to study the influence of variation of both feed and cutting speed during machining on the tool life. Firstly a relation has been developed with the help of experimental data correlating flank wear with such parameters as velocity, feed and cutting force due to flank wear. Using this relation and the law of adhesion wear, finally an equation of tool life is established. An optimization program is used which takes cutting force due to flank wear as input and gives the optimized values of cutting speed and feed as output. The program enables to know when and by how much the values of cutting speed and feed are to be changed during cutting for maximizing tool life.

Chapter 2

Theoretical Analysis

2.1 Adhesion tool wear model and tool life equation:

In deriving the tool wear model, adhesion has been considered as the predominant wear mechanism, since cutting is performed at low speeds and feeds. It is also assumed that the workpiece is homogeneous and free of segregated carbides and inclusons so that abrasion wear is absent.

When two mating surfaces are brought together, they touch at the tips of the higher asperities. The real area of contact supports the load and increasing the normal load increases the amount of deformation and contact area, thus increasing the number of asperities which support the load.

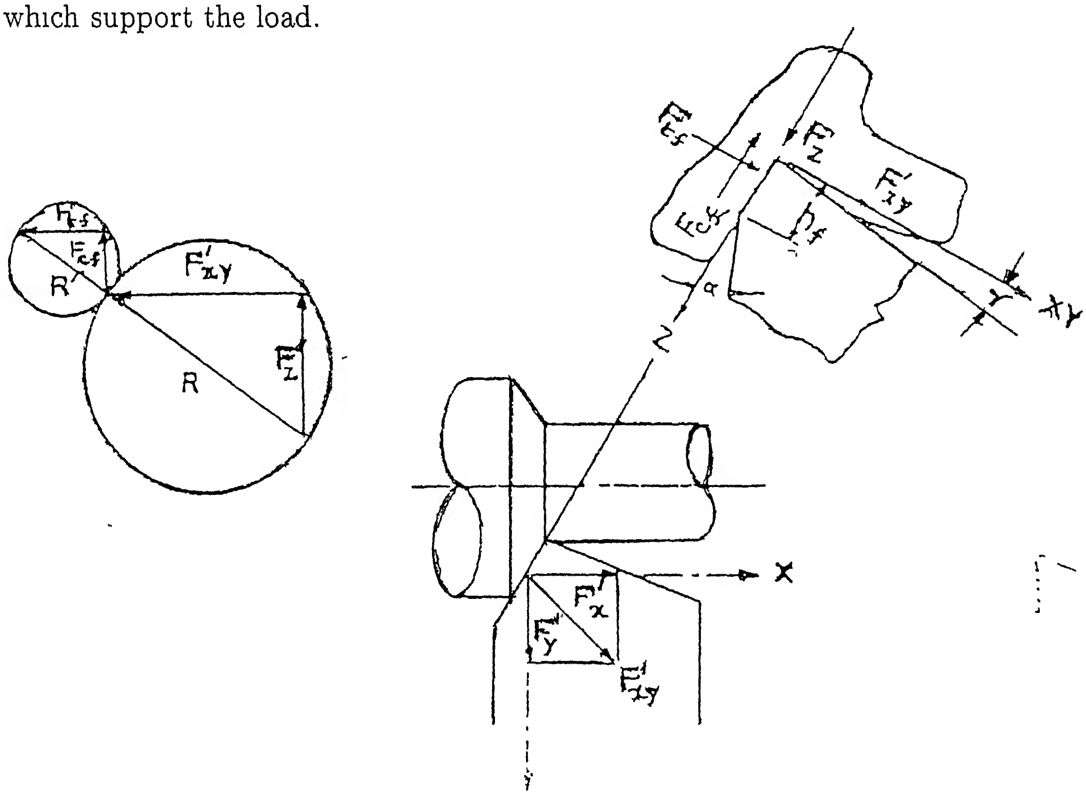


Fig. 2.1 Relationship of flank wear and cutting force systems on worn tool, Ref[23]

When sliding of the mating surfaces takes place, the asperities of the harder material slide over the softer material causing plastic deformation and wear of a thin layer of material. As sliding continues frictional heat builds up and at a certain temperature, depending upon the materials and frictional surface conditions, particles of one material adhere to the other and fracture from the parent material causing plastic lump wear.

As the cutting time progresses, cutting tool wears out and a wear land devoleps at the principle flank surface as shown in the Fig2.1 . Due to this wear land formation two additional forces known as normal

and frictional forces act at the principle flank as a result of contact between the tool flank surface and the finished workpiece surface in the direction of thrust and cutting forces respectively. Hence the thrust force (F_xy) and cutting force (F_z) consists of two parts.

$$F_{xy} = F'_{xy} + F_{tf} \tag{2.1}$$

$$F_z = F'_z + F_{cf} \tag{2.2}$$

where F'_{xy} and F'_z are thurst and cutting force components to deform the material in the absence of wear (when $h_f = 0$)

$F_{tf} and F_{cf}$ = Increments of thrust and cutting forces acting at the flank wear land.

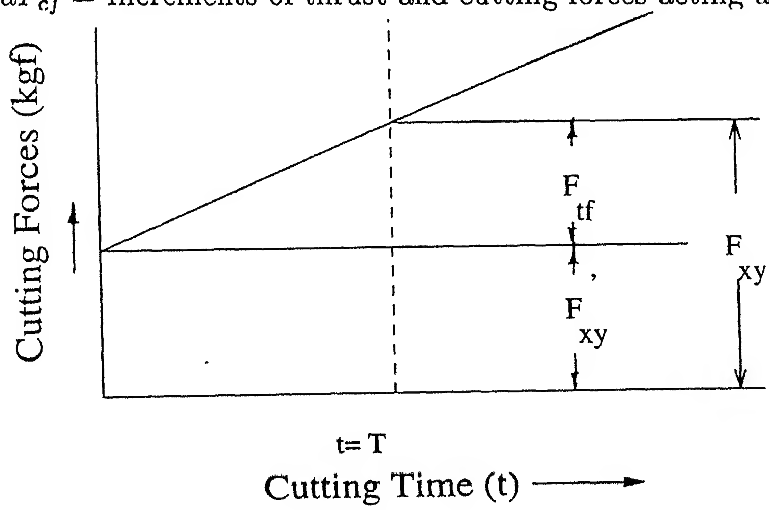


Fig. 2.2 Force characteristics with time when wear grows, Ref[23]

For cutting with variable parameters (i. e speed, feed etc), growth of F_{tf} andF_{cf} depend upon velocity, feed, flank wear land and depth of cut . However depth of cut is treated as constant.

Hence, F_{tf} and F_{cf}can be written as [18]

$$F_{cf} = Kv^a f^b h_f^c \tag{2.3}$$

$$F_{tf} = K_1 v^a f^b h_f^c \tag{2.4}$$

where, v = cutting velocity , f = feed and h_f = flank wear height where, K, K_1, a, b and c are constants to be evaluated by experiments.

According to the fundamental law of adhesion wear[19]

Adhesion wear volume per unit length (flank) is proportional to F_{tf}

$$\frac{dV_A}{dl} \propto F_{tf}$$

$$\frac{dV_A}{dl} = \frac{z}{BHN} F_{tf} \tag{2.5}$$

where dV_A is adhesion wear volume, z is wear coefficient of tool and work material combination and BHN is brinnel hardness of work material.

$$\frac{dV_A}{dl} = CF_{tf}$$

where,

$$C = \frac{z}{BHN} = constant$$

since,

$$dl = vdt$$

$$\frac{dV_A}{dt} = CF_{tf}v$$

Substituting the value ofF_{tf} from equation(2.4)we get,

$$\frac{dV_A}{dl} = CK_1 v^{a+1} f^b h_f^c \tag{2.6}$$

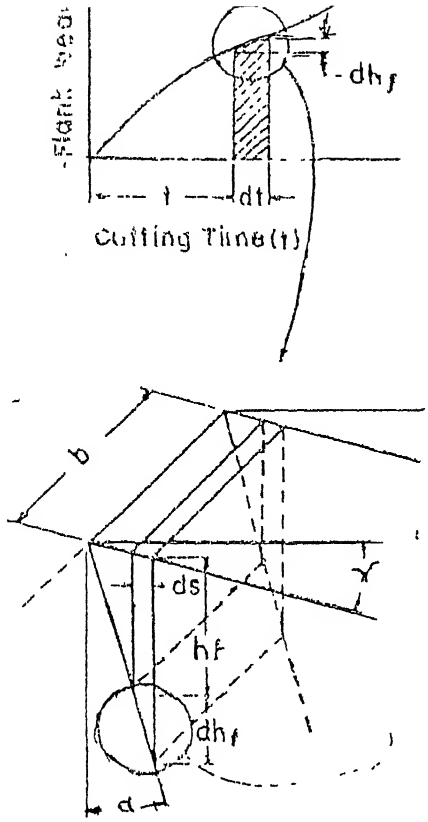


Fig. 2.3 Elemental flank wear volume(dV) at time interval(dt), Ref[23]

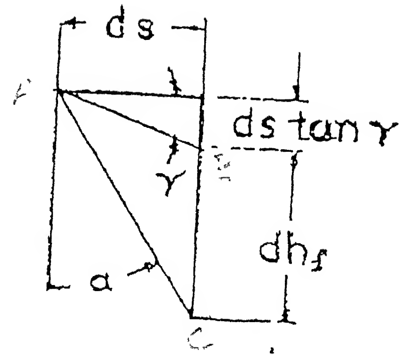


Fig. 2.4 Geometry of tool tip, Ref[23]

Fig. 2.3 shows the geometry of a worn out tool.

From the Fig. 2.3, the volume of the worn out tool material at any instant during a time interval ofΔt is dV, which is given by,

$$dV = b[h_f ds - [\frac{1}{2}ds(dh_f + ds\tan\gamma) - \frac{1}{2}ds(ds\tan\gamma)]$$

$$dV = bds(h_f + \frac{dh_f}{2})$$

γ α

where b = width of cut, $\cancel{\alpha}$ andγ are rake and clearance angles respectively

From the Fig. 2.4 considering $\triangle ABC$

$$\begin{aligned} AB &= \frac{ds}{\cos\gamma} \\ BC &= dh_f \\ \angle BAC &= 90 - (\alpha + \gamma) \\ \angle ACB &= \alpha \end{aligned}$$

Applying the sine rule,

$$\begin{aligned} \frac{AB}{\sin\alpha} &= \frac{BC}{\sin(90 - (\alpha + \gamma))} \\ \frac{ds}{\cos\gamma\sin\alpha} &= \frac{dh_f}{\cos(\gamma + \alpha)} \\ ds &= \frac{dh_f\cos\gamma\sin\alpha}{\cos\gamma\cos\alpha - \sin\gamma\sin\alpha} \\ &= \frac{dh_f}{\cot\alpha - \tan\gamma} \\ &= \frac{dh_f\tan\alpha}{1 - \tan\alpha\tan\gamma} \\ Therefore, dV &= b(\frac{dh_f\tan\alpha}{1 - \tan\alpha\tan\gamma})(h_f + \frac{dh_f}{2}) \end{aligned}$$

α = rake angle

γ = clearance angle

Neglecting the dh_f^2 terms,

$$dV = bh_f(\frac{dh_f\tan\alpha}{1 - \tan\alpha\tan\gamma})$$

$$dV = bh_f\psi_o dh_f \tag{2.7}$$

where $\psi_o = \frac{\tan\alpha}{1 - \tan\alpha\tan\gamma}$

ψ_o is constant for given tool geometry,

upon differentiating equation (2.7) w. r. t. time, we get the value of the flank wear volume rate as,

$$\frac{dv}{dt} = bh_f\psi_o\frac{dh_f}{dt}$$

where, the width of cut can be expressed as:

$$b = \frac{d}{\cos\psi}$$

where, d = depth of cut

ψ = side cutting edge angle

Therefore,

$$\frac{dv}{dt} = \frac{d}{\cos\psi}\psi_o \; h_f\frac{dh_f}{dt}$$

or the expression for the wear volume rate could be further simplified as

$$\frac{dV}{dt} = K_2 h_f\frac{dh_f}{dt} \tag{2.8}$$

where,

$$K_2 = \frac{d}{\cos\psi}$$

Since it is has been assumed that cutting process is performed at moderate speeds such that the temprature generated at the tool work interface is not high, therefore neglecting crater wear, it can be written that,

Wear volume rate, $\frac{dV_A}{dt}$ = Flank wear rate, $\frac{dV}{dt}$

Equating equations (2.6) and (2.8)

$$\begin{aligned} CK_1v^{a+1}f^bh_f^c &= K_2h_f\frac{dh_f}{dt} \\ or, \frac{dh_f}{dt} &= C\frac{K_1}{K_2}v^{a+1}f^bh_f^{c-1} \\ \frac{dh_f}{h_f^{c-1}} &= C\frac{K_1}{K_2}v^{a+1}f^bdt \end{aligned}$$

Integrating both sides,

$$\begin{aligned}\int \frac{dh_f}{h_f^{c-1}} &= C\frac{K_1}{K_2}v^{a+1}f^b \int dt \\ \frac{h_f^{1-c+1}}{1-c+1} &= C\frac{K_1}{K_2}v^{a+1}f^b t + c_1\end{aligned}$$

At time t = 0, $h_f = 0$

$$\Rightarrow c_1 = 0$$

$$\begin{aligned}\frac{h_f^{2-c}}{2-c} &= C\frac{K_1}{K_2}v^{a+1}f^b t \\ h_f &= [\frac{CK_1(2-c)}{K_2}]^{\frac{1}{2-c}} v^{\frac{a+1}{2-c}} f^{\frac{b}{2-c}} t^{\frac{1}{2-c}}\end{aligned}$$

$$\Rightarrow h_f = C_1 v^{\alpha} f^{\beta} t^{\gamma} \tag{2.9}$$

$$\begin{aligned}C_1 &= [\frac{CK_1(2-c)}{K_2}]^{\frac{1}{2-c}} \\ &= constant \\ and, \alpha &= \frac{a+1}{2-c} \\ \beta &= \frac{b}{2-c} \\ \gamma &= \frac{1}{2-c}\end{aligned}$$

t = Cutting time , becomes the tool life when h_f reaches the threshold criterion (0. 8mm). From equation(2.9),

$$\Rightarrow t = (\frac{h_f}{C_1 v^{\alpha} f^{\beta}})^{\frac{1}{\gamma}} \tag{2.10}$$

2.2 Penalty function method [4]

The cutting time in the tool life equation derived(eqn 2.10) has to be maximized with respect to some practical constraints like velocity, feed and MRR etc. to ensure maximum tool life. In order to do so, a proper constrained optimization technique, has to be chosen. Penalty function method, has been chosen to serve the above purpose. The algorithm, originally in FORTRAN has been converted to TURBO C to ensure its compatibility with the language of the interfacing program.

Penalty fuction method works in a series of sequences, each time modifying a set of penalty parameters, and starts a sequence with the solution in the previous sequence. Penalty function method is basically a gradient based method as discussed in the first chapter. This algorithm includes cauchy's steepest descent method, and bounding phase method.

The cauchy's steepest descent method finds the gradient of the function, in the direction where lies the minimum of the function, where as bounding phase find the intervals of the parameters for which the function is minimum.

The detailed flow chart of the whole program is depicted in Fig3 6.

where M = Maximum number of iterations.

$x_i(0)$ = Initial values of velocity and feed, [i=1..n].

m, p, r = Penalty parameters.

n = No. of variables.

$g_j(x)$ = Constraint equations.

m = No. of constraints.

P = Penalty function.

Formulation of equations:

In the above program,

objective function(f) is,

Maximize,

$$f = t = (\frac{h_f}{C_1 v^{\alpha} f^{\beta}})^{(\frac{1}{\gamma})}$$

constraints are,

$$v_{min} \leq v \leq v_{max}$$

$$f_{min} \leq f \leq f_{max}$$

$$MRR = v \star f \star d$$

since 'd' is assumed as constant,

$$MRR = K \star v \star f$$

$$MRR_{min} \leq MRR \leq MRR_{max}$$

Chapter 3

Instrumentation

3.1 Dynamometer:

The measurement of cutting forces is performed either by measuring directly the deflection of the tool due to the cutting forces with the help of dial gauges (Mechanical dynamometer) or indirectly by measuring the deformation suffered by a transducing element(strain gauge) due to the deflection of the tool The most most widely used dynamometers employ transducing elements which convert mechanical deformations into electrical signals. Various

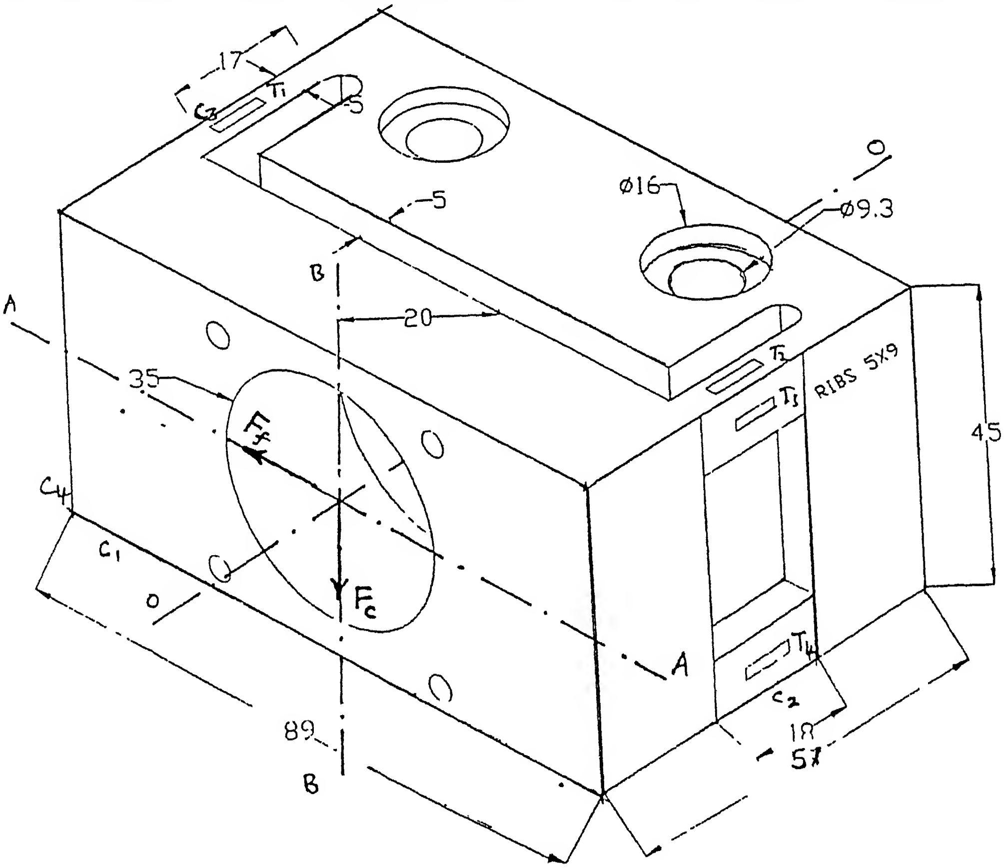


Fig 3 1 Dynamometer

forms of transducing elements which are used to convert mechanical deformations into electrical signals are (i) capacitive, (ii) piezo-electric, (iii) inductance, (iv) strain gauge pick-up. A two component cutting force dynamometer of cantilever type is used in the present work. The design of the dynamometer is illustrated in Fig. 3.1 The dynamometer structure is made of aluminium. The action of the forces is to bend the structure. The cutting force F_c bends the structure about the axis A-A and the Feed force F_f bends the structure about axis B-B. Strain gauges were used to measure these distortions (moments), and the recordings are calibrated to give a measure of the forces applied. Bonded wire strain gauges with resistance 120 ohms and gauge factor 2, have been used Strain gauges were cemented with guaging wires parallel to the dynamometer axis O-O. The free end of the dynamometer structure has a square hole into which the tool is inserted as shown in the Fig. 3.2

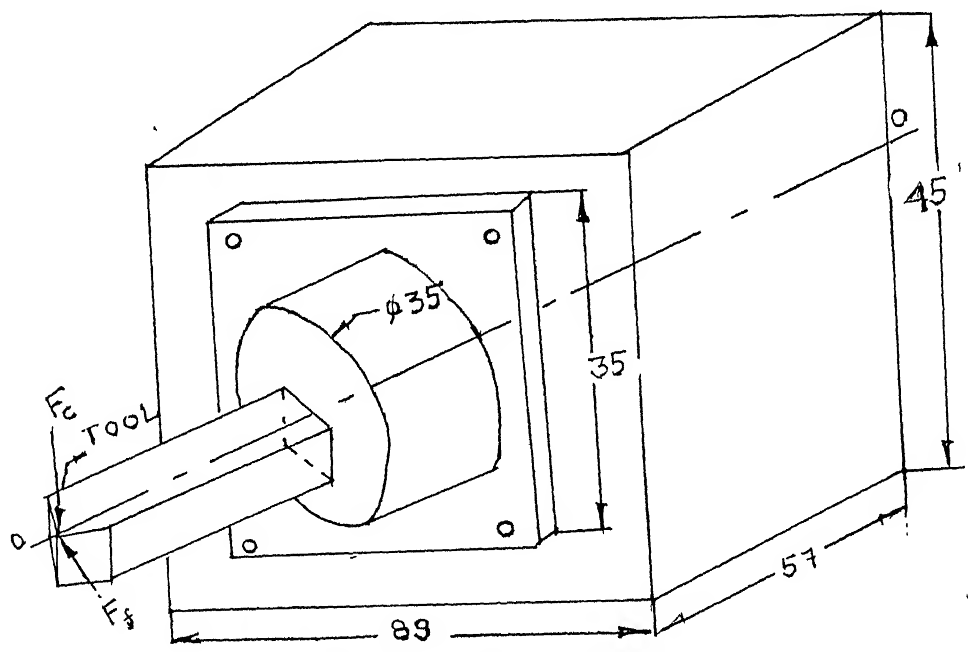


Fig 3.2 Tool holder

To measure the moment M_c due to cutting force F_c two gauges are cemented to the

top of the measuring section T_1 , T_2 and two more gauges $C_1$and C_2 are cemented directly below them. Thus, when M_c is applied , two gaugesT_1, $T_2$are subjected in tension, while two othersC_1, C_2 receive an equal amount of compression, thereby satisfying the requirements for a complete Wheatstone bridge as shown in Fig.3.3(a). In a similar manner moment M_f, due to feed force F_f, is measured by four gauges T_3, T_4, C_3, C_4 which are cemented as shown in Fig3.3(b).

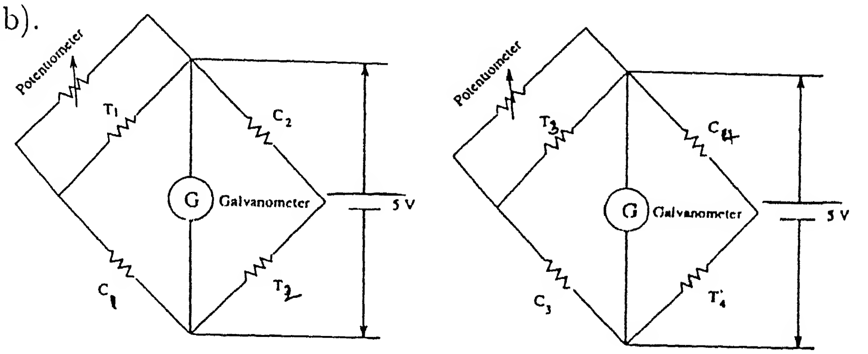


Fig. 3.3 Bridge circuits for measuring F_c and F_f

3.2 Amplification circuit

A pre-amplification circuit has been designed and fabricated using a special purpose operational amplifier. The circuit is shown in the Fig 3. 4 An operational amplifier amplifies

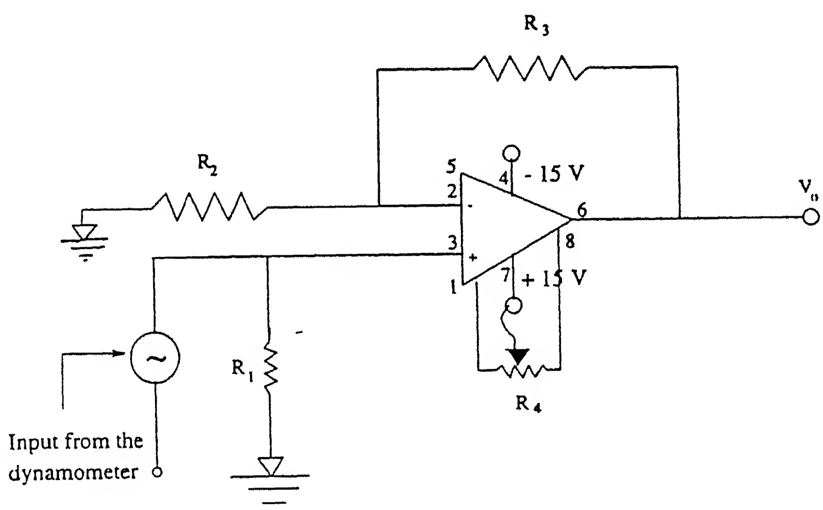


Fig. 3.4 Amplification circuit

the difference in the voltage signals at the two inputs, and can operate either in inverting or non-inverting mode. The voltage developed across the load resistor of the transducer R1, is fed as one input to the op-amp, the other input is grounded with another resistor R2, R3 being the feedback resistor. Required factor of gain is obtained by using appropriate values of the two resistors, R3 and R2. Initially with the two input s of the op-amp shorted and grounded, the output voltage is set to zero using the variable resistor R4. This is called the input offset voltage correction. This is to be done carefully before using the circuit otherwise the op-amp will be driven into a saturation region giving a constant output voltage for any input signal. The gain used in the present work is calculated as follows: Gain(G) =(1+ R3/R2). The output voltage is found as Vo = G (V3 - V2). = (1 + R3/R2) (Ip R1). I_p = Input current to the Amplifier.

3.3 Analog to digital conversion:

The amplified signal from the sensing and amplification circuit is to be converted into digital form before feeding it to the optimisation program. Of the various techniques available for

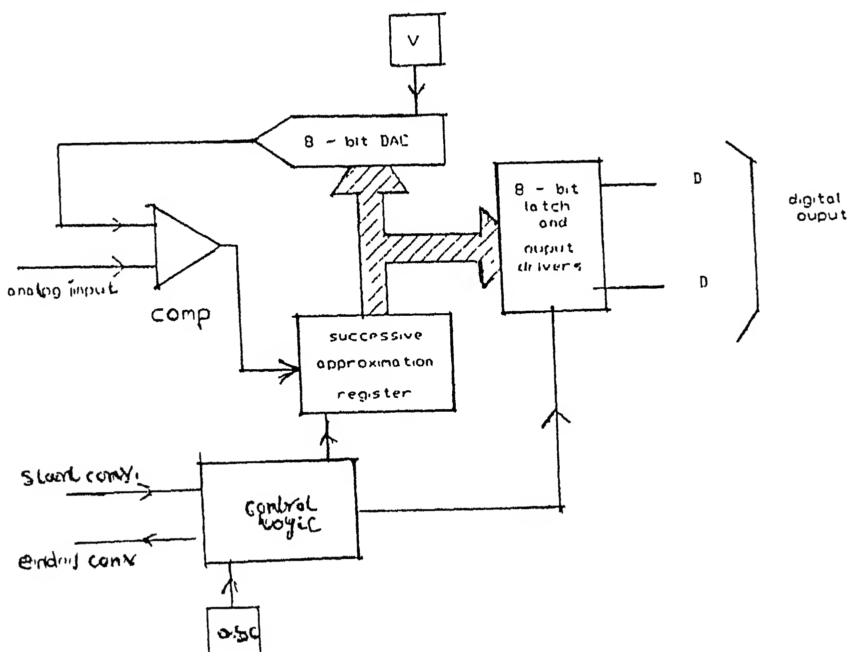


Fig. 3.5 Successive approximation ADC, Ref[20]

A/D conversion, Successive Approximation Method is the most popular method [19]. In this technique, various output codes are fed into a D/A converter and the result is compared with the analog input via a comparator, as shown in Fig 3.5. The way it is usually done is to set all bits initially to zero, and begining with the most significant bit, each bit in turn is set to one. If the D/A output does not exceed the analog input sinal voltage, the bit is left as a one, otherwise it is set back to zero. For an n-bit A/D, n such steps are required. A successive approximation A/D module has a BEGIN OF CONVERSION input and END OF CONVERSION output. The digital output is always provided in the parallel format. Successive approximation A/D converters are relatively accurate and fast, requiring only 'n' settling times of the DAC for n -bit precision. This type of converter operates on a brief sample of the input voltage and if the input voltage is changing during the conversion, the error is not greater than the change during that time.

A commercially available data acquisition card for IBM PC/XT/AT computers PCL-812 from Dynalog Microsystems Ltd, is used in present work. This uses an industrial standard 12-bit successive approximation converter ADC574 to convert the analog inputs. The specifications and features of this card are shown in Appendix.

The A/D conversion is triggered using a software, controlled by the application program issued software command. The data transfer is also done using the program control. After the A/D converter has been triggered, the application program checks the END OF CONVERSION (EOC) bit of the A/D status register. If the EOC is detected, the converted data is transferred from the A/D data register to computer memory by the application program control, Fig3.6 shows the algorithm used for writing the application program for the A/D conversion.

It provides a method for transferring binary information between internal storage such as memory and CPU registers and external I/O devices. Peripherals connected on-line to computer need special commu nication links for interfacing them with the central processor. The purpose of communication link is to resolve the differences that exist between the central processor and peripheral device. The flow of data is as shown in Fig 3.7.

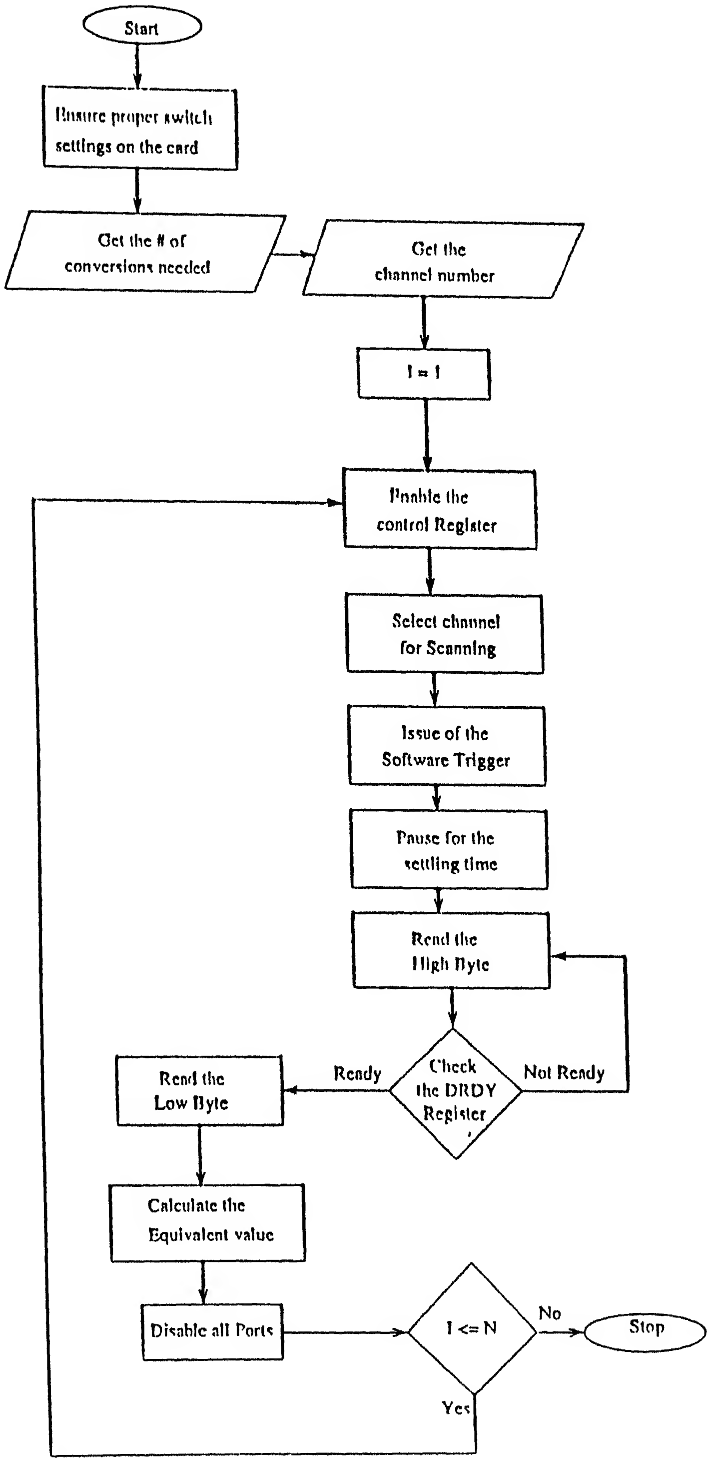


Fig. 3.6 Flow chart of ADC

3.4 PC Interfacing:

It provides a method for transferring binary information between internal storage such as memory and CPU registers and external I/O devices. Peripherals connected on-line to computer need special commu nication links for interfacing them with the central processor. The purpose of communication link is to resolve the differences that exist between the central processor and peripheral device. The flow of data is as shown in Fig 3.7.

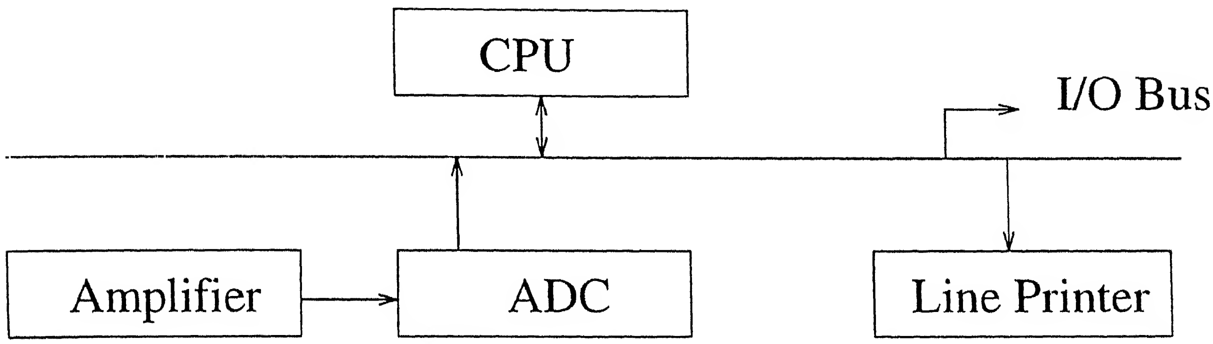


Fig. 3.7 Flow of data between CPU and Peripherals, Ref[21]

Data transfer between the central computer and peripheral can take place through program control. Program controlled operations are result of I/O instructions written in the computer program. Each data item transfer is indicated by an instruction in the program. Usually, the transfer is to and from a processor register such as accumulator and peripheral. Another instruction is needed to transfer the data to and from the accumulator and memory. Transferring the data under program control requires constant monitoring of the peripheral flag to see when a transfer can be made. It is upto the processor to keep close tabs on everything that is taking place in the interface unit. Transfer of data under program control is through I/O bus and between processor and peripheral.

Chapter 4

Experimentation

The whole set of experiments was carried out in two stages. Experiments in the first stage were devoted to evaluate the constants involved in the equation (2.3), which has been the basis for the derivation of tool life equation: Experiments conducted in the second stage were used to assess the improvement in the tool life. A schematic diagram of the experimental set up used in first stage is shown in Fig 4.1. The bridge circuits(Fig3.3) for

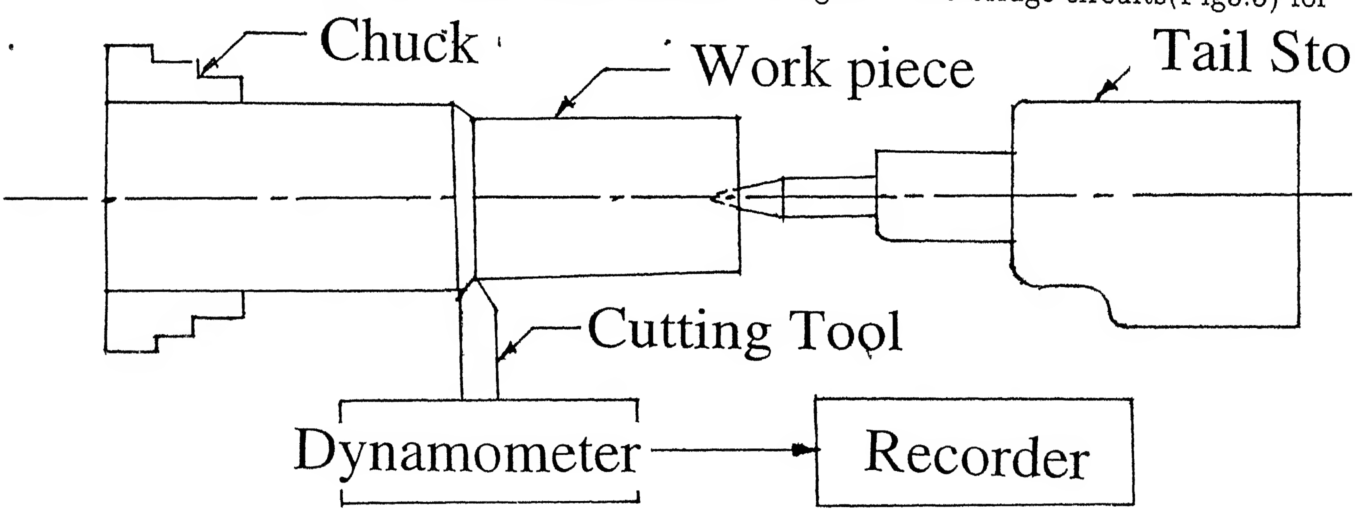


Fig. 4.1 Schematic diagram of initial experimental setup

measuring the forces are balanced to give zero reading initially with the help of variable resistor. Tool height and the tool overhang are set to the required levels with the help of gauges. The workpiece was held in a four jaw chuck and supported by a center in the

tail stock. A rough turning pass was made to eliminate the run-out of the workpiece. The experimental data were taken in 3 sets. Depth of cut is kept constant throughout the experiment. In the first set , velocity and feed are kept constant , and the flank wear height h_f was measured at appropriate intervals. A metallurgical microscope having graduations marked on the eye piece was used to measure the flank wear height. At each value of flank wear height, the corresponding value of cutting force due to wear F_{cf} was noted. In the second set, feed is kept constant and machining is carried out at diffrent velocities . For each value of velocity, cutting force due to wear and flank wear height h_f were measured at different intervals. In third set, velocity is kept constant and feed is varied. The values of cutting forces due to wear F_{cf} and flank wear height h_f were measured and noted as explained above. With the help of the above data, values of K,a,b, and c were calculated.

Schematic diagram of the experimental set up in the second stage is shown in Fig4.2.

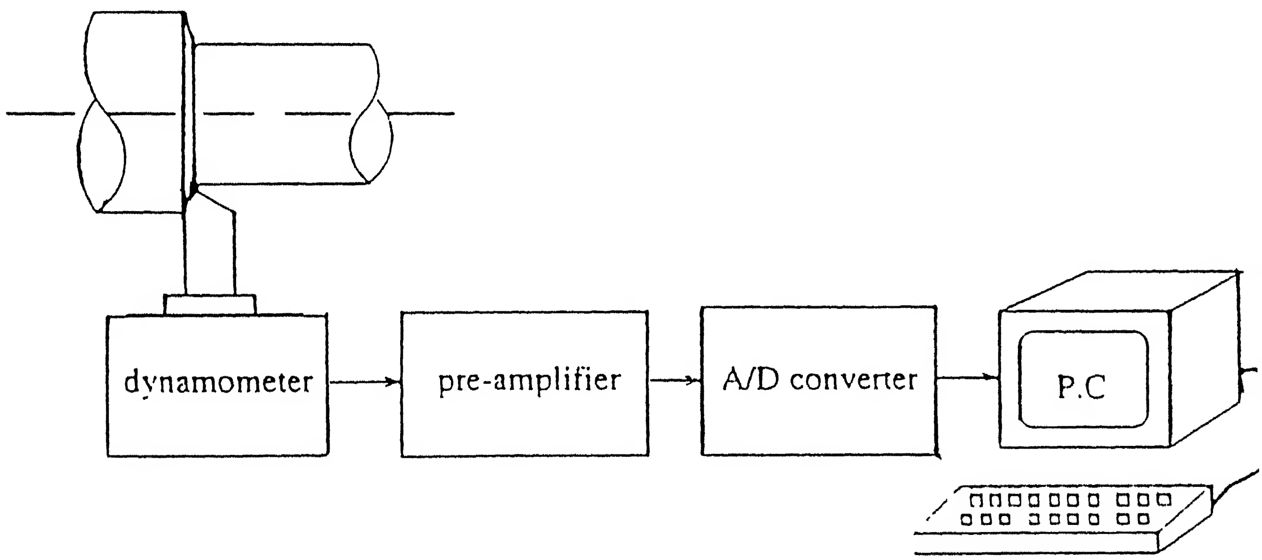


Fig. 4.2 Schematic diagram of final experimental setup

The dynamometer is calibrated to correlate the signal voltage with that of the force acting on the tool. Before using the amplification circuit the input voltage offset should be corrected using the variable resistor R4(Fig3.4)in the circuit. The circuit should give a zero output when the two inputs to the operational amplifier are short circuited and groundede. The operational amplifier is powered using a regulated D. C. power supply model No HIL 3161. The required gain of the amplifier is obtained by the use of suitable resistors R3 and R2 in the circuit. The amplified signal is then fed to the analog-to-digital card mounted inside the IBM PC. Initial switch settings are made on the analog-to-digital card for selecting the operating range. Using the software a trigger is passed to the converter indicating the START OF CONVERSION and on receiving the END OF CONVERSION signal the converted data is transfered to a particular memory location. It is programmed to obtain the data after every 0.1 sec. After every 100 conversions the average of all the 100 readings is found and is taken as the output signal of A/D converter. Averaging of the values is done to take care of the small variations. The signal value is converted to appropriate force unit. Knowing the force, velocity, and feed, the flank wear height h_f is calculated with the help of equation equation(2.3) above. The above calculation is programmed in the code. This value of flank wear height h_f given is fed to as input to the optimisation program. The other inputs to the program are velocity and feed at which the machine is operating. The program correspondingly optimises the velocity and feed for maximum tool life and gives the modofied values of velocity and feed. The machine is stopped and velocity and feed are adjusted to the modified values and started again. The whole process i. e. getting force value from signal, calculation of flank wear, feeding it to the program, modifying the operating velocity and feed is continued until the flank wear height reaches or exceeds 0. 8 mm signalling the end of the tool life. Time intervals for attaining different flank wear heights are noted down with the help of stop watch, during the experiment. The total time elapsed for the tool to attain flank wear of 0. 8mm is measured from the graph.

give the minimum required MRR. Force value is obtained from the ADC signal . Knowing the force, velocity and feed, flank wear height is calculated and time taken to attain particular flank height is noted.The same procedure is repeated keeping the velocity and feed constant through out the experiment.The time corresponding to flank wear of 0.8mm is noted from the graph,which becomes the tool life in this case. The tool lifes obtained in both the cases are compared and the percent improvement in the tool life is noted down.

Chapter 5

Results and Discussion

For the experiments two sets of tool work combinations are used to verify the applicability of the model discussed previously . One is high carbon steel with HSS tool having no cobalt and the other is EN24 steel work material with HSS having 10%cobolt. The material compositions and tool geometry are as given in the appendix. The tool geometry, tool height and tool overhang are maintained uniformly for all the experiments. Depth of cut is 0.3mm which is kept constant for all the expriments.

In the first stage the cutting conditions (ie. velocity feed and depth of cut) and the output parameters (i. e cutting force due to flank wear, and the flank wear onthe cutting tool) obtained are shown in tables 5.1-5.5 and 5.6-5.10 for each tool work combinations. Relationships between cutting force due to wear and flank wear height were plotted for various cutting conditions as shown in figures 5.1 to 5.6.

From the above curves it can be observed that the increase in the cutting force is influenced by the feed and velocity taken in that order. Using the above data the values of a, b, c and K of equation(2.3) are calculated. The range of variation of each constant is mentioned for each tool material combination. From this range of variation , a particular value of each constant has been selected such that percent is within 12%. The results obtained in the second stage are shown in tables 5.11-5.14. For each reading the flank wear height h_f and the time in which it occurs is noted . The above results are for both cases i.

e keeping the velocity and feed constant and in the other one, velocity and feed are vari(as given by the program. Graphs plotted for the above values are shown in the figures 5 and 5.8. It was observed that there is an improvement by 22% for HSS-HCS combinatic and 34% for HSS-EN24 combination.

The increase in the tool life, by decreasing the velocity and increasing the feed can t attributed to following reasons. Since the machining is carried out at below the averag speeds, the chip tool interface temperature is not high. Also the increase in the feed wi increase the chip tool contact length. This causes better distribution of heat, reduc(both flank and crater wear rates and increases the tool life. Also since the machining carried out close to the optimum values of velocity and feed it was possible to use th minimum values of cutting speed enhancing the tool life, since the decrease in velocity accompanied by an increse in the feed so that MRR constraint is satisfied through out th cutting process.

Some limitations were encountered in the experiment. R.P.M, and feeds are bot available in steps in engine lathe on which the experiment is done. This limitation force to excercize judgement and adopt the values close to the available range.

The following are the results for HSS and EN24 combination.

At,,v=46.57m/min.,,f=0.275mm/rev.

S. No.	Flank wear (mm)	Measured cutting Force (kgf)	Theoretical cutting Force (kgf)
1	0.26	5.92	6.30
2	0.43	10.11	11.10
3	0.56	13.40	13.50
4	0.68	15.83	18.60
5	0.86	19.37	19.50
6	0.96	21.30	21.75
7	1.13	24.50	25.30
8	1.27	27.10	27.60

: Table for calculation of Constant 'c'

Range of variation of 'c' = 0.74-0.99.

Chosen value of 'c' = 0.86.

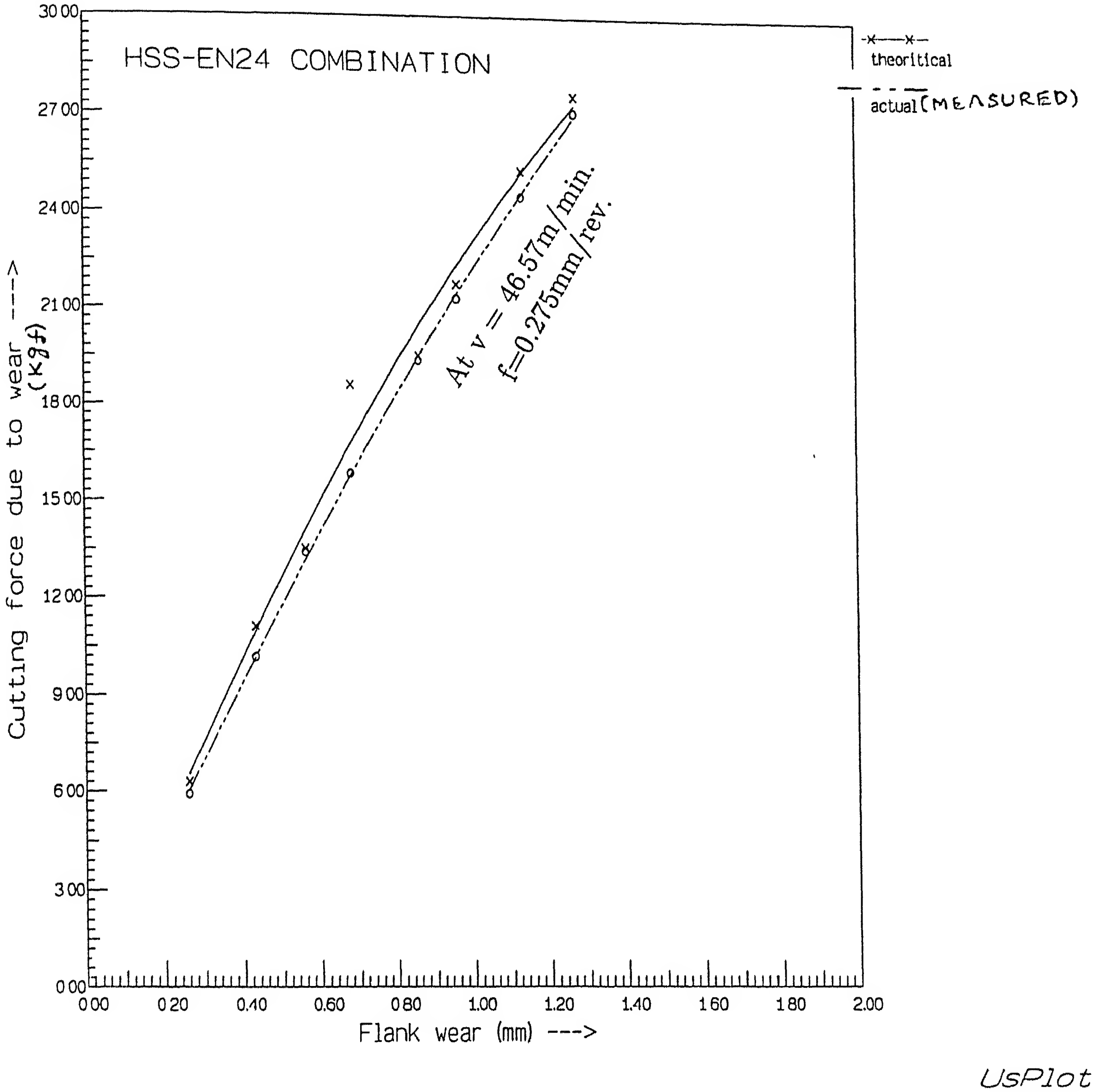


Figure : variation of cutting force F_{cf} with flank wear

f=0.275mm/rev.

S. No.	Flank Wear (mm)	Velocity (m/min)	Measured cutting Force (kgf)
1	0.187	23.64	2.8
2	0.190	38.2	5.6
3	0.431	30.86	8.5
4	0.434	47.04	13.75
5	0.53	47.04	13.5
6	0.91	47.04	24.45

Table 5.2: Table for calculation of Constant 'a'
Range of variation 'a' = 0.979-1.185.
chosen value of 'a' = 1.12

S. No.	Flank wear (mm)	Measured cutting Force (kgf)	Theoretical Cutting Force (kgf)
1	0.53	12.92	13.5
2	0.83	19.0	20.1
3	0.97	21.73	23.75
7	1.12	28.11	31.65
8	1.22	30.82	31.95

Table 5.3: Values at v = 47.4m/min

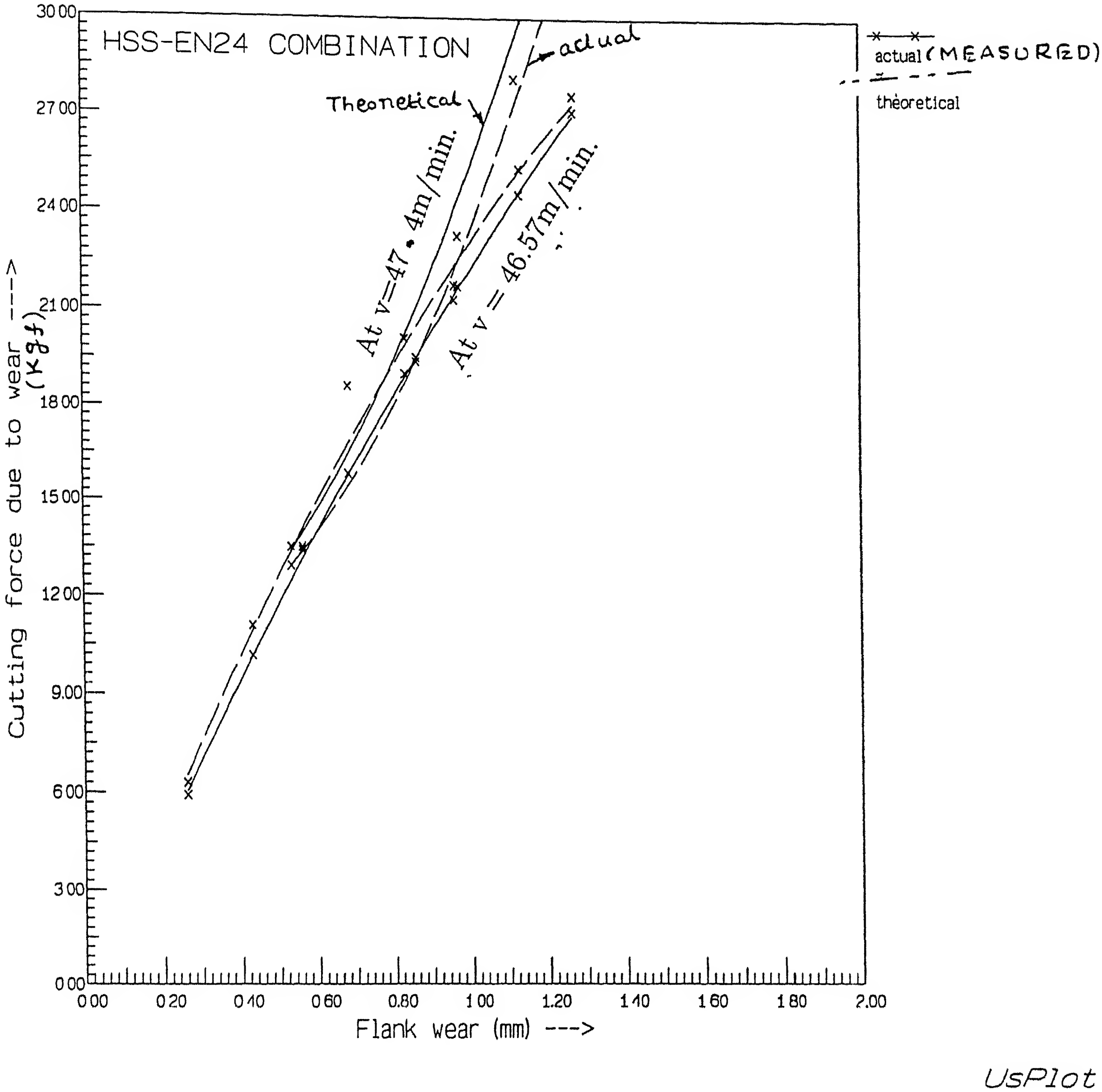


Figure 5.2: variation of cutting force with flank wear

v=46.57m/min.

S. No.	Flank Wear (mm)	Cutting Force (kgf)	Feed (mm)
1	0.24	2.8	0.175
2	0.5	4.2	0.15
3	0.49	5.2	0.168
4	0.77	15.1	0.25
5	1.0	16.2	0.25
6	0.2	6.8	0.2
7	0.55	14.4	0.3

Table 5.4: Calculation of Constant 'b'
Range of variation of 'b'= 1.2-1.9.
Chosen value of 'b'= 1.55.

S. No.	Flank wear (mm)	Measured cutting Force (kgf)	Theoretical cutting Force (kgf)
1	0.55	15.09	14.4
2	0.68	18.12	18.43
3	0.89	22.83	25.95
4	0.95	24.15	29
5	1.03	31.63	32.1

Table : values at f= 0.3 mm/rev

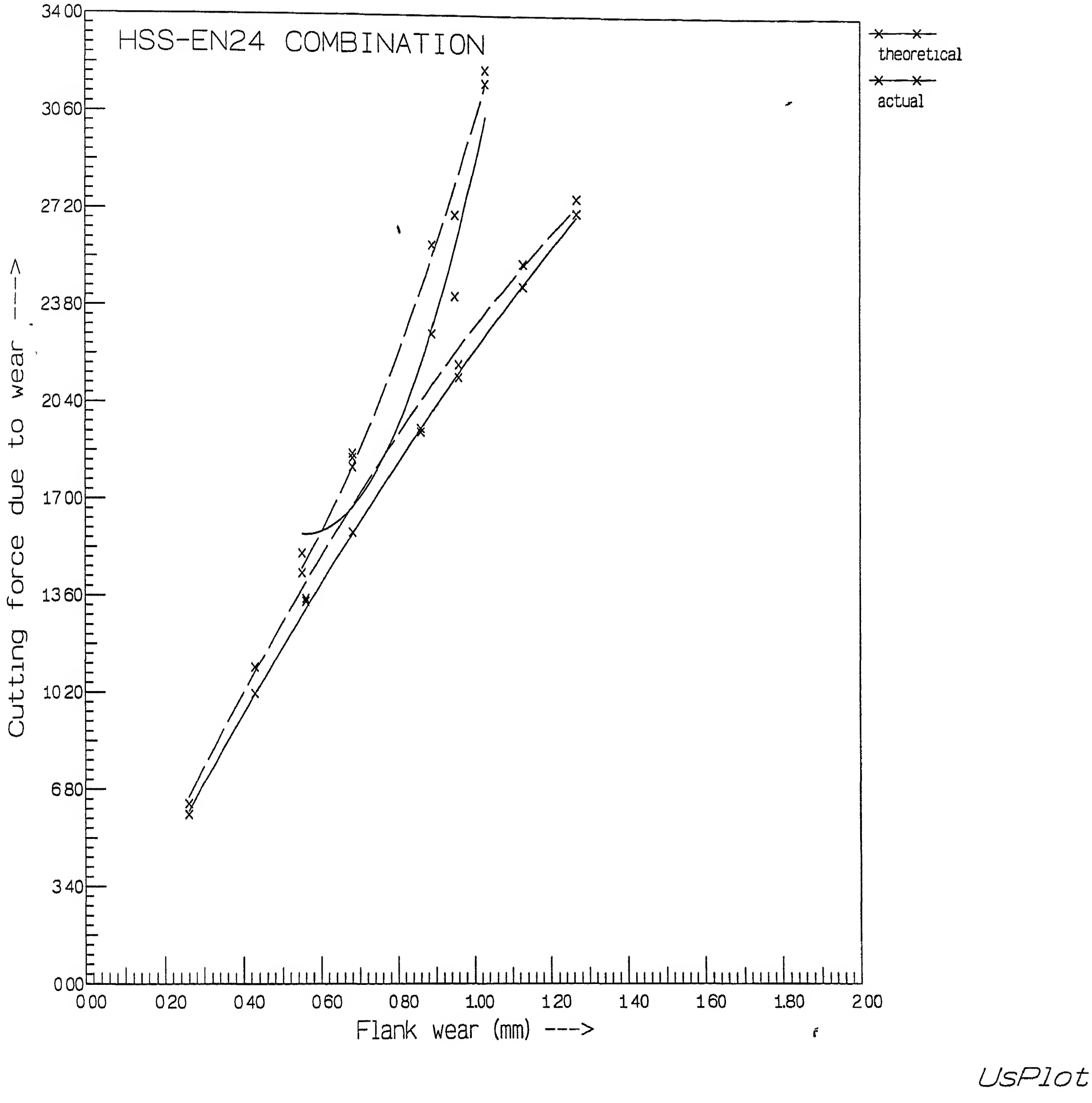


Figure 5.3: variation of cutting force with flank wear

After substituting the values of a, b, c in the equation (2.3),the value of K is calculated using the values of cutting force F_{cf} and flank wear given in the table 5.1. Range of variation of K is 2.04 - 2.3. Chosen value of K is 2.21. Therefore,

$$F_{cf} = 2.21 v^{1.12} f^{1.55} h_f^{0.86}$$

z = wear coefficient $= 7.7 * 10^{-4}$[24]

$$\begin{aligned} C &= \frac{z}{BHN} \\ &= \frac{7.7 * 10^{-4}}{254} \\ &= 3.3 * 10^{-6} \end{aligned}$$

Increment of thrust force acting at the flank wear land can be expressed as:

$$F_{tf} = F_{cf} \tan(\beta - \gamma_o)[23]$$

β = friction angle $= 33.2^\circ$

γ_o = Orthogonal rake angle $= 6.9^\circ$

$$\begin{aligned} K_1 &= K \tan(\beta - \gamma_o) \\ &= 2.21 \tan(33.2 - 6.9) \\ &= 1.1 \\ K_2 &= \frac{d}{\cos\psi}\left[\frac{\tan\alpha}{1 - \tan\alpha \tan\gamma_o}\right] \end{aligned}$$

where, d = 0.3 mm

$$\begin{aligned} \gamma_o &= 6.9^\circ \\ \psi &= 7^\circ \\ \alpha &= 7^\circ \\ \Rightarrow K_2 &= 0.029 \end{aligned}$$

From the above values, calculated value of c_1 is

$$C_1 = 5.45 * 10^{-4}$$

$$where, C_1 = [\frac{CK_1(2-c)}{K_2}]^{\frac{1}{2-c}}$$

Therefore, the tool life equation (2.10) in final form is

$$h_f = 5.45 * 10^{-4} v^{1.86} f^{1.36} t^{0.87}$$

The following are the results for HSS and High carbon steel combination.
At, v=15.7m/min, f=0.05mm/rev.

S. No.	Flank wear (mm)	Measured cutting Force (kgf)	Theoretical cutting Force (kgf)
1	0.51	4.4	4.9
2	0.77	6.7	6.79
3	0.94	7.9	7.4
4	1.26	10.74	10.4
5	1.32	11.06	10.5
6	1.51	12.6	12.1
7	1.57	13.09	13.0
8	1.63	13.5	13.1
9	1.82	15.1	15.5
10	2.0	16.56	17.0

Table for calculation of Constant 'c'

Range of variation of 'c'= 0.95-1.01.

Chosen value of 'c' = 0.97.

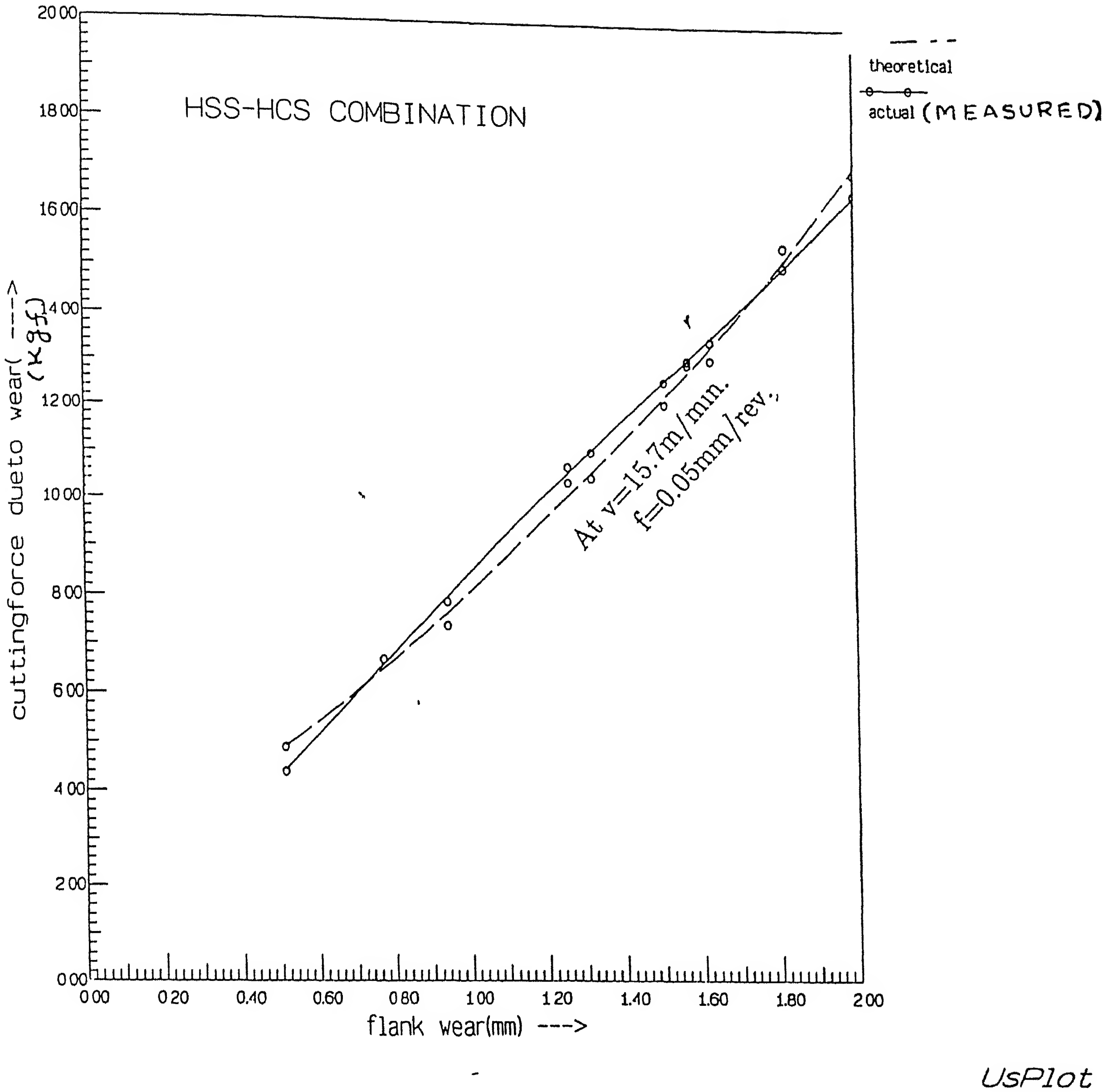


Figure 5.4: variation of cutting force with flank wear

f=0.05mm/rev.

S. No.	Flank Wear (mm)	velocity (m/min)	Cutting Force (kgf)
1	0.3	12.62	4.2
2	1.32	15.7	10.51
3	1.63	19.71	18.0
4	1.56	15.7	12.3
5	2.0	15.7	17.1
6	1.25	25.23	21.4

Table F Table for calculation of Constant 'a'
Range of variation of 'a'= 1.57-1.9.
Chosen value of 'a'=1.78.

S. No	Flank Wear (mm)	Measured Cutting Force (kgf)	Theoretical Cutting Force (kgf)
1	0 4	7.0	7.9
2	0.79	10.98	13.17
3	1.12	18.64	21.90
4	1.25	20.95	23.2
5	1.3	24.5	25.3

Table — values at v = 25.23 m/min

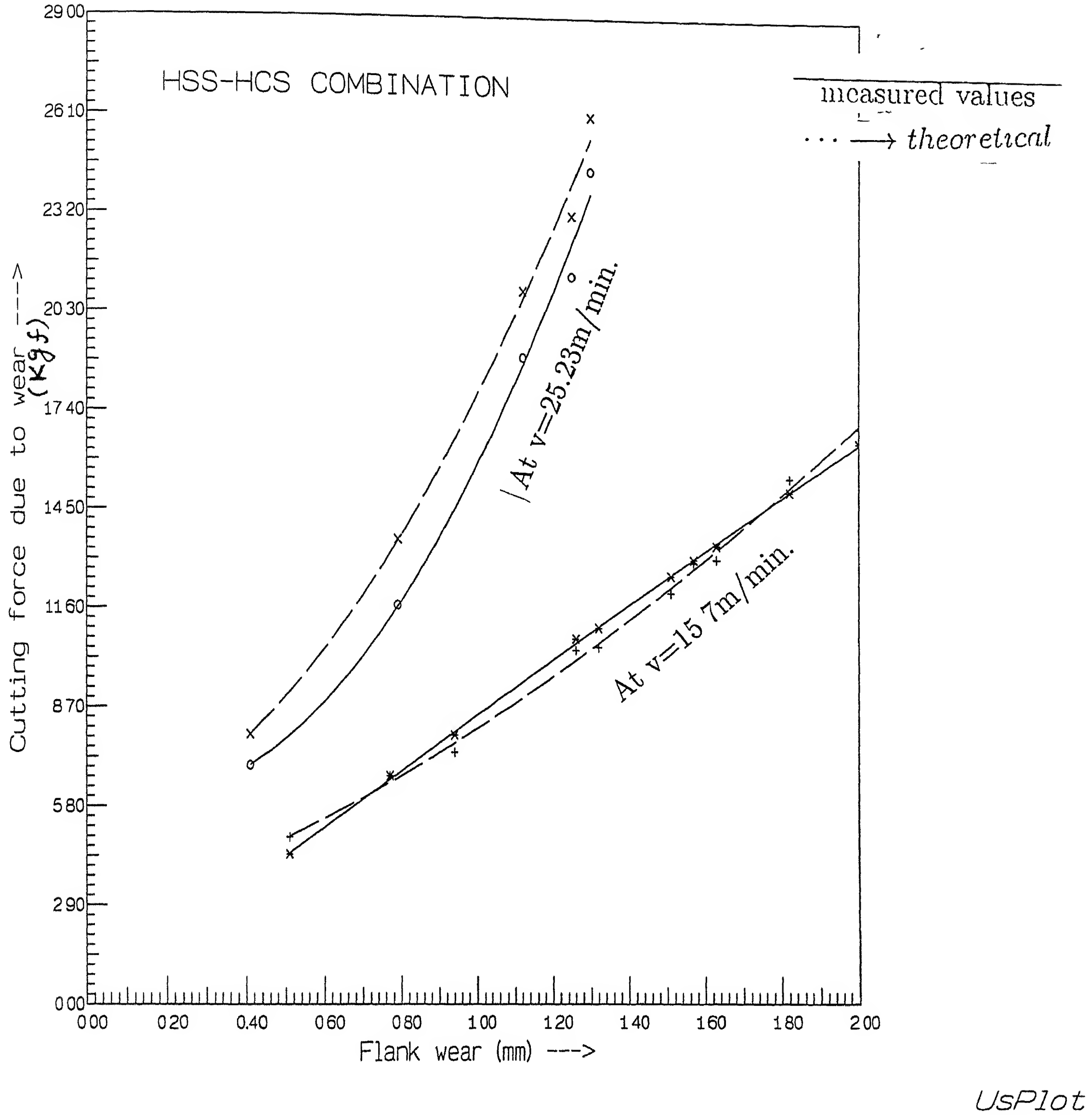


Figure 5.5: variation of cutting force with flank wear

[Table 5.6; 5.8:]

v=15.7m/min.

S. No.	Flank Wear (mm)	Measured cutting Force (kgf)	Feed (mm/rev)
1	1.5	12.1	0.05
2	1.63	13.2	0.05
3	1.82	15.5	0.05
4	1 38	15.4	0.063
5	1.28	13.6	0.063
6	1.52	22.3	0.063
7	0.53	6.0	0.075
9	1.38	11.8	0.075
8	0.48	8.8	0.088
9	1.43	21.8	0.088

Table 5.9: Table for calculation of Constant 'b'
Range of variation of 'b'= 1.78-1.9.
Chosen value of 'a' = 1.83.

S. No.	Flank Wear (mm)	Measured cutting Force (kgf)	Theoretical Cutting Force (kgf)
1	0.85	9.82	7.4
2	1.04	13.4	10.9
3	1.21	15.52	13.4
4	1.28	14.3	13.6
5	1.38	17.63	15.4
6	1.52	20.37	22.3

Table 5.10: values at f= 0.063mm/rev

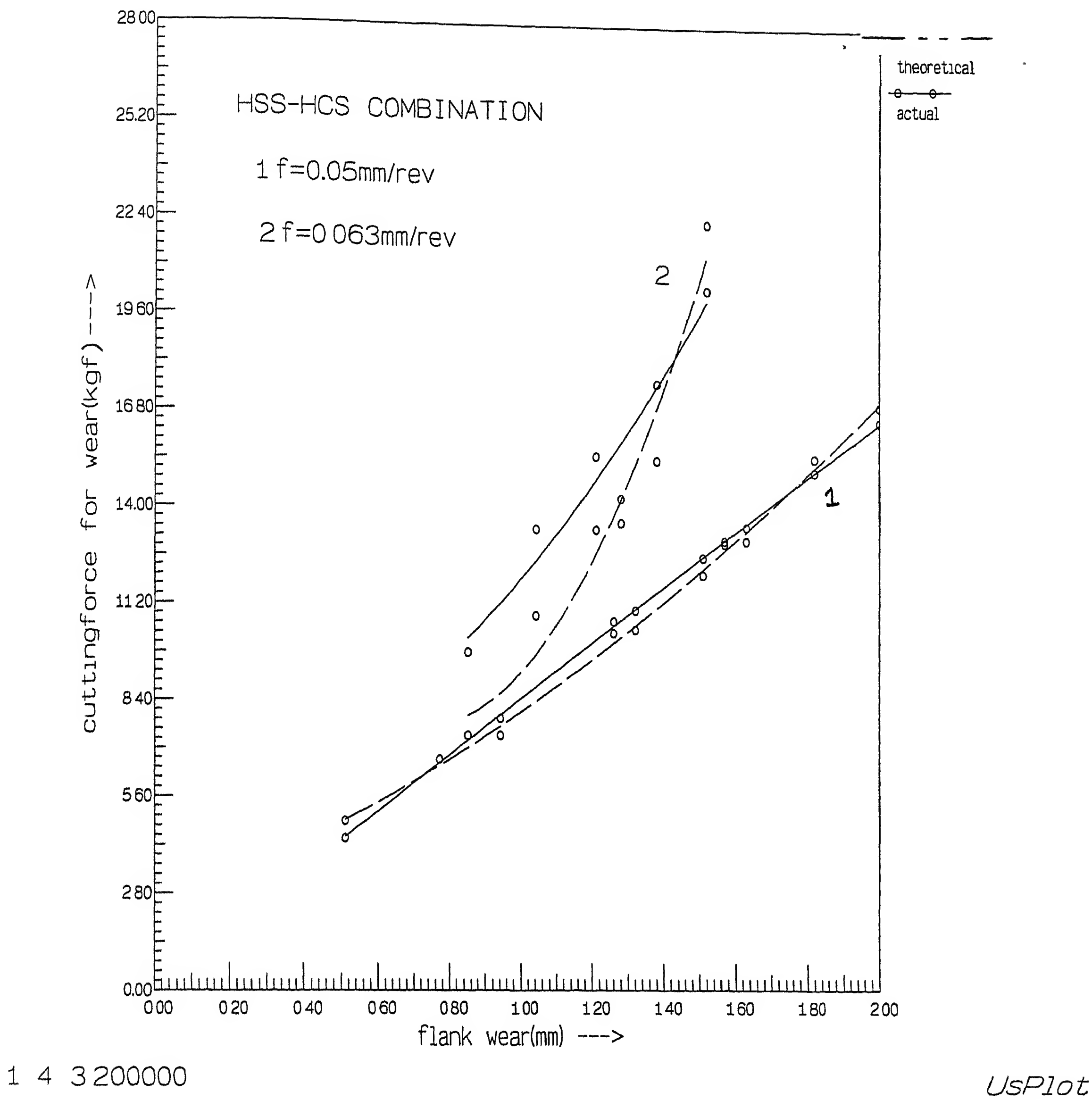


Figure 5.6: variation of cutting force with flank wear

After substituting the values of a, b, c in the equation (2.3), the value of K is calculated using the values of cutting force F_{cf} and flank wear given in the table 5.6. Range of variation of K is 14.8 to 15.4. Chosen value of K is 15.11. Therefore,

$$F_{cf} = 15.11 v^{1.78} f^{1.83} h_f^{.97}$$

z = wear coefficient = $6.7 * 10^{-3}$[24]

$$\begin{aligned} C &= \frac{z}{BHN} \\ &= \frac{6.7 * 10^{-3}}{266} \\ &= 2.518 * 10{-}5 \end{aligned}$$

Increment of thrust force acting at the flank wear land can be expressed as:

$$F_{tf} = F_{cf} \tan(\beta - \gamma_o)[23]$$

β = friction angle = 33.2

γ_o = Orthogonal rake angle = 9.7

$$\begin{aligned} K_1 &= K \tan(\beta - \gamma_o) \\ &= 15.11 \tan(33.2 - 9.7) \\ &= 6.3 \\ K_2 &= \frac{d}{\cos\psi} \frac{\tan\alpha}{1 - \tan\alpha \tan\gamma_o} \end{aligned}$$

where, d = 0.3 mm

$$\begin{aligned} \gamma_o &= 9.7 \\ \psi &= 13 \\ \alpha &= 7 \\ \Rightarrow K_2 &= 0.038 \end{aligned}$$

From the above values, calculated value of C_1 is

$$C_1 = 6.64 * 10^{-3}$$
$$where, C_1 = [\frac{CK_1(2-c)}{K_2}]^{\frac{1}{2-c}}$$

After substituting the above values of constants, the equation(2.10) in its final form is

$$h_f = 6.64 * 10^{-3} v^{2\ 69} f^{1\ 77} t^{0.96}$$

For HSS and High carbon steel combination the following are the constraints equations used. Objective function,

Maximize,

$$t = (\frac{h_f}{6.64 * 10^{-3} v^{2\ 69} f^{1\ 77}})^{(}1.03) \tag{0.1}$$

Subjected to, Constraints,

$$12 < v \leq 20m/min \tag{0.2}$$

$$0.05 \leq f \leq 1.0 \tag{0.3}$$

f in mm/rev

$$MRR = v * f * d$$

d= 0.3 mm (constant)

$$0.72 \leq MRR \leq 0.78 \tag{0 4}$$

S. No.	Flank Wear (mm)	Time (min)
1	0.0	0.0
2	1.6	0.115
3	1.96	0.14
4	2.9	0.2
5	3.4	0.245
6	4 1	0.26
7	5.5	0.36
8	7.0	0.385
9	8.7	0.515
10	9.5	0.54
11	10.8	0.91

Table 5.11: With single values of v and f,At v=15m/min. f=0.05mm/rev.

S. No	Flank Wear (mm)	Time (min)
1	0.0	0.0
2	1 5	0.1
3	2.2	0.13
4	3.3	0.18
5	4.4	0.215
6	5.7	0.285
7	7 6	0.33
8	8 6	0.395
9	9.2	0.475
10	11.4	0.51
11	12.1	0.815

Table 5.12: With optimised values of v and f
Speed range adopted 32-40rpm.
Feed range adopted 0.05-0.069mm/rev.

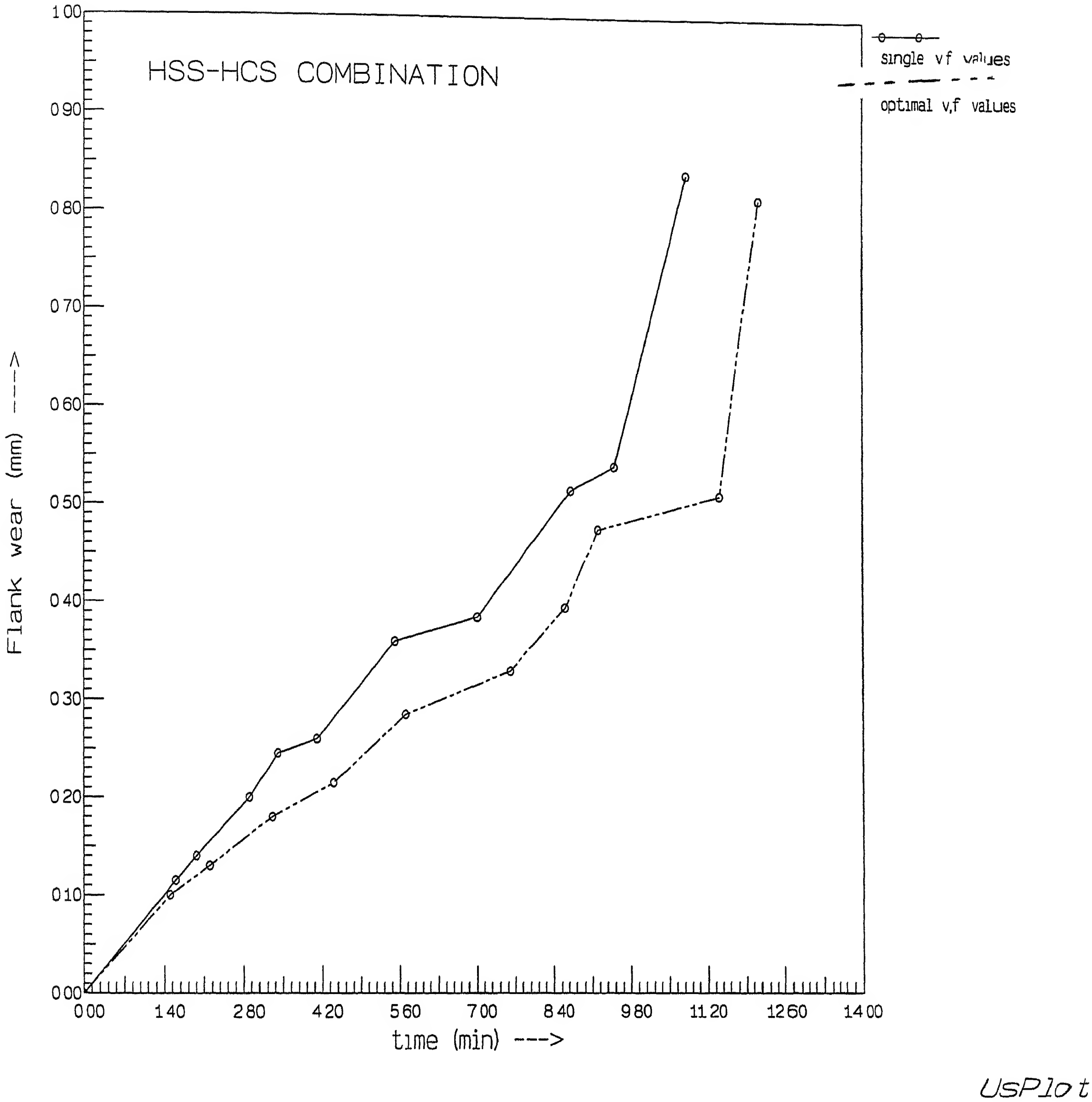


Figure 5 7: variation of flank wear with time

For HSS and EN24 steel combination the following are the constraints equations used.

Objective function,

Maximize,

$$t = (\frac{h_f}{5.45 * 10^{-4} v^{1.86} f^{1.36}})^(1.03) \quad (5.5)$$

Subjected to, constraints,

$$35 < v \leq 48 m/min \quad (5.6)$$

$$0.05 < f \leq 1.0 \quad (5.7)$$

f in mm/rev

$$MRR = v * f * d$$

d= 0. 3 mm (constant)

$$12.2 \leq MRR \leq 12.6 \quad (5.8)$$

S. No.	Flank Wear (mm)	Time (min)
1	0.0	0.0
2	1.3	0.145
3	1.9	0.175
4	3.4	0.275
5	5.1	0.38
6	6.1	0.445
7	7.98	0.495
8	9	0.545
9	10.5	0.72
10	11.6	0.901

Table 5.13: With single values of v and f,At v=45m/min. f=0.275mm/rev.

S. No.	Flank Wear (mm)	Time (min)
1	0.0	0 0
2	1.7	0.13
3	2.7	0.175
4	3.4	0.22
5	4 4	0.245
6	5 3	0.305
7	6.7	0.355
8	8.3	0.405
9	9.5	0.46
10	10.9	0.49
11	11.9	0.515
12	13.1	0.62
13	14.8	0.785
14	15.3	0.83

Table 5.14: With optimised values of v and f
Speed range adopted = 200-250rpm.
Feed range adopted = 0.275-0.35mm/rev.

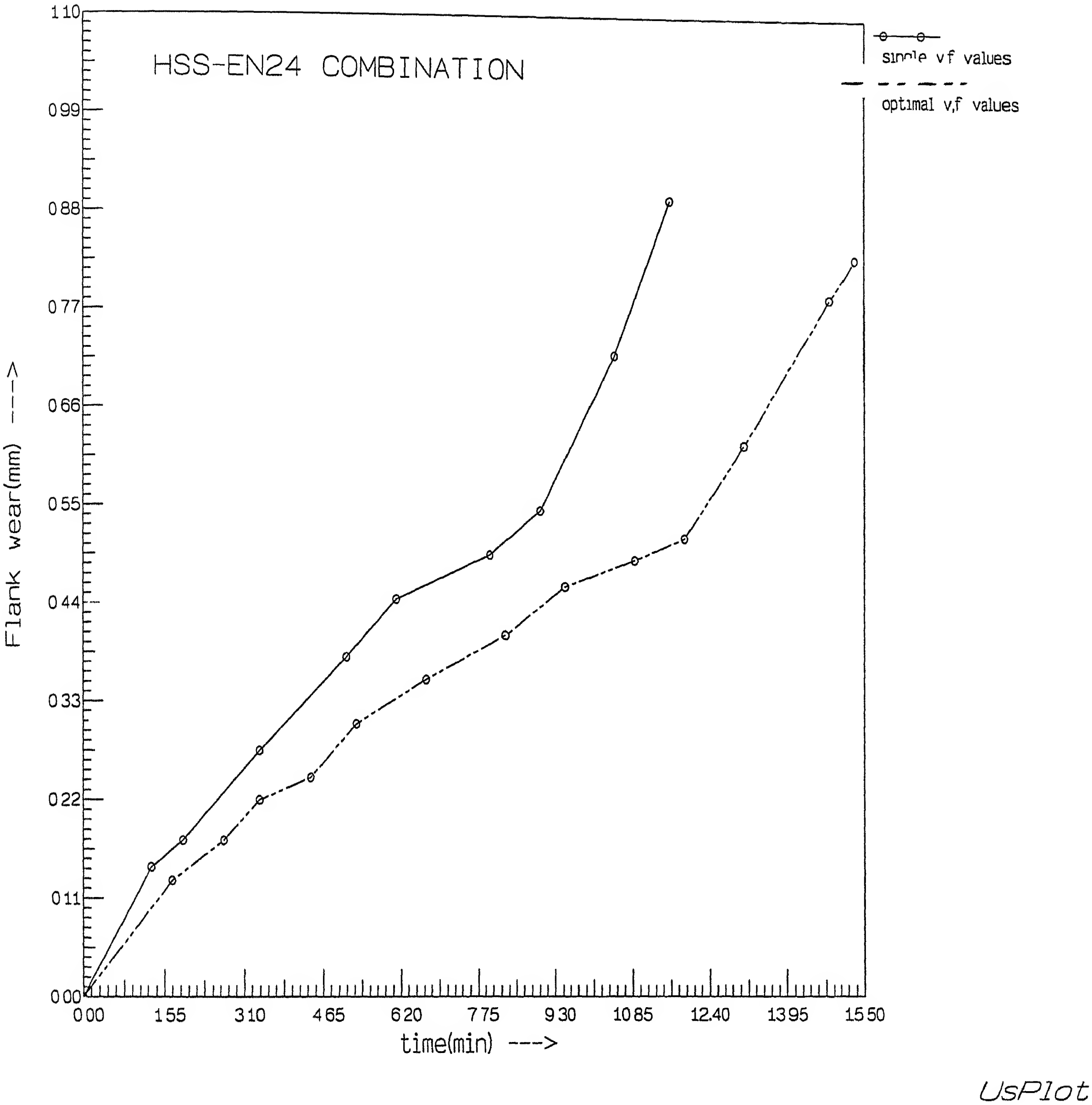


Figure 5.8: variation of flank wear with time

Chapter 6

Conclusions and scope for future work

6.1 Conclusions

An optimization technique has been used to machine under optimal parameters of speed and feed. The basic idea is to reduce the slope of the flank wear-time curve, so that tool life can be improved to the maximum possible extent.

The following objectives have been fulfilled.

- Establishment of tool life equation.
- Developing the amplification circuit.
- Developing the appilication program for analog-to-digital conversion.
- Conversion of optimization program into "TURBO C" langauge to make it compatibl with the operating system.

The performance of the system has been tested experimen tally in the allowble rang of machining conditions for two different sets of workpiece and cutting tool material com bination. Results showed substantial improvement in the tool life in both the cases.

6.2 Scope for future work

The following are the prospective areas, which have been identified for future work as given below.

- The above mathodology if applied on CNC machine can give still better results , since velocity and feed can be maintained to the exact values as were recommended by the optimization program.

- The system can be used for other machining processes such as milling with the help of suitible wear model .

- Study of the above method on a large set of work-tool combination.

- Other practical constraints like surface finish, chatter, power etc, can be included in the program to make it suitable for a specific appilication.

References

1 P.C.Sharma, " Production engineering", *S.chand Publishers*, India(1993).

2. A Bhattacharya, " Metal cutting:Theory and practice", *Central book publishers*, Culcutta, India(1984)

3. N H.Cook, " Tool wear and tool life", *ASME:Journal of engineering for industry* " , Vol 95, No.4, p 931(Nov 1973).

4. K.Deb, " Optimization methods in Engineering design", *Prentice Hall of India ltd*, India(1995).

5. S.S.Rao, " Optimization theiry and applications", *Wiley eastern ltd, Delhi*, India(1984).

6 M.Balazinski, E.Ennajimi, " Influence of feed variation on tool wear when milling stainless steel 17-4 ph", *ASME:Journal of engineering for industry*, Vol.116, pp 516-520, Nov 1984.

7. K.Mondalski, " Study of influence of feed variations on tool wear", *ASME Proceedings*, vol.43, pp 115-122, 1990.

8. M.Balczinski, V.Songmene, " Tool life improvement through variable feed milling of inconel 600", *Annals of CIRP*, vol 44/1/1995, pp 55-58.

9. J.Jamienick, M.Szafarczyk, " Difficulties in tool life predicting when turning with variable cutting parameters" , *Annals of CIRP*, Vol.34/4/1985. pp 113-116.

10. J.Takatsuto, R.Mitsuo, M.Kishi, M.Kozo, " Chip disposal system using an intermittently deceelarated drilling feed technique", *Bull.Japan Soc.of precision Engg*, vol 24, No 1, Mar 1990, pp 27-32.

11. A.Novak, N.Linkpong, H.Wilkund, " On-line prediction of tool life" *Annals of CIRP*, Vol.45/1/1996, pp 93-96.

12. K.Nagasaka, N.Hashimoto, " Establishment of tool life equation considering the amount of tool wear" ,*Wear* 81(1982), pp 21-31.

13 E.Usui, T.Shirakashi, T.Kitagawa, " Analytical Prediction of cutting tool wear", *Wear* 100(1984), pp 129-151.

14. G.Barrow, " Tool life equations and machining economics", *Proceedings of 12th MTDR conference* (1971), pp 481-493.

15 C Rubenstein, " An analysis of tool life based on flank-face wear" *ASME: Journal of engineering for industry*, Vol 98, Feb 1976, p 221.

16 K S.Lee, L.C.Lee and S.C.Teo, " On line tool wear monitering using a PC" *Journal of Material processing and technology*, Vol 29(1992), pp 3-13.

17 S Raman, R.K.Lakkaraju, " Incorporation of tool life variables in NC path Turning" *International journal of production reasearch*, Vol 30, No 11, Nov 1992, pp 2545-2558.

18 P Martin, J.Richard,and M.Veron, " The influence of speed variations on tool wear for optimal control of machining", *Annals of CIRP*, Vol 28/1/1979, pp 7-11.

19. J.T.Burwell, C.D.Strang, " On the empirical law of adhesive wear", *Journal of applied physics*, Vol 23, No 1, Jan 1952, pp 18-28.

20. P.Horowitz, W.Hill, " The Art of electronics", *Cambridge university press*(1992).

21 M.Moris Mano, " Computer system Architechture", *Prentice Hall of India ltd*, Delhi(1986).

22. S.B.Rao, " Tool wear monitoring through the dynamics of stable turning", *ASME:Journal of engineering for industry*, Vol 91, August 1969, pp 790-798.

23. A.Bhattacharya, I.Ham, " Analysis of Tool wear part1,Models of flank wear", *ASME:Journ of engineering for industry*, Vol 91, August 1969, pp 790-798.

24. Kragelski.V.I, " Friction and wear", *Butterworths Publishers* , Washington,1965.

Appendix

Work material	: EN24 steel,High carbon steel.
Workpiece specifications	: (i) EN24 steel, 0.35-0.45%C; 0.45-0.6% Mn; 1.3-1.8% Ni; 0.9-1.4%Co; 0.2-0.3%Cr; 0.1-0.35%Si; rest is iron.
	: (ii) High carbon steel, 0.5-0.6%C; 0.35-0.5% Mn; 0.3-0.4% Si; rest is iron.
Workpiece hardness	: 254BHN(EN24), 266BHN(High carbon steel).
Cutting tool materials	: HSS, HSS with high cobalt.
Cutting tool composition	: i)HSS 18%W,4%Cr,1.5%V, ii)EN24 18%W,4%Cr,2%V,10%Co.
Tool geometry	: i)HSS, 0-10-7-8-10-13-0mm. ii)HSS with high cobalt, 0-7-7-8-14-7-0mm.
Specifications of lathe	: Center height 180mm. Center distance 1000 mm. Swing over bed 350mm. Swing over crossslide 180mm. spindle speeds 32-1600RPM. feeds 0.05-1 4mm/rev.